No. XII.

Papers on Various Subjects connected with the Survey of the Coast of the United States. By F. R. Hassler.—Communicated 3d March, 1820.

CIRCULAR LETTER.

Treasury Department,
25th March, 1807.

SIR,

The President of the United States being authorised by an Act of the last Session to cause the whole of the coast of the said States, together with the adjacent shoals and soundings to be surveyed, it is his intention that the work should be executed with as much correctness as can be obtained within a reasonable time; and he has directed me to apply to you, requesting that you would have the goodness to suggest the outlines of such a plan as may, in your opinion, unite correctness and practicability.

As each nautical survey of the shoals and soundings, presupposes a knowledge of the position of certain points of the coast, it seems to me that the work should consist of three distinct parts, viz.:

1. The ascertainment, by a series of astronomical observations, of the true position of a few remarkable points on

the coast; and some of the light houses, placed on the principal capes or at the entrance of the principal harbours, appear to be the most eligible places for that purpose, as being objects particularly interesting to navigators, visible at a great distance, and generally erected on spots on which similar buildings will be continued so long as navigation exists.

2. A trigonometrical survey of the coast between those points of which the position shall have been astronomically ascertained; in the execution of which survey, the position of every distinguishable permanent object should be carefully designated, and temporary beacons be erected at proper distances on those parts of the coast on which such objects are rarely found.

3. A nautical survey of the shoals and soundings of the coast, of which the trigonometrical survey of the coast itself, and the ascertained position of the light houses and other distinguishable objects would be the bases; and which would therefore depend but little on any astronomical observations made on board the vessels employed on that part of the work.

But this is submitted to your consideration not for the purpose of pointing out any plan in preference to another, but only in order to shew the view which we have taken of the subject, and the degree of accuracy which we are desirous of obtaining.

I will only add, that the greatest practical difficulties which have heretofore occurred, relate to what I call the nautical survey; and on that part of the subject the following inquiries have arisen:—Can a correct survey be taken with one vessel alone? Can angles be taken with sufficient correctness from on board a vessel, so as to ascertain its position in relation to three visible objects on shore? Or is it necessary that the vessel's position, at the time of taking any particular sounding, should be ascertained by observers on shore? And many others which an examination of the subject will naturally suggest to you.

Permit me also to ask, whether you know any person whom you might recommend as capable of acting in the different parts of the work.

I have the honour to be

Respectfully,

Your obedient servant,

(Signed) ALBERT GALLATIN.

Mr. Hassler,
Philadelphia.

Philadelphie, 2 Avril, 1807.

MONSIEUR,

Honoré de votre lettre du 25 Mars passé, je prends la liberté de répondre à la confiance que vous voulez bien me montrer, et de vous communiquer mes idées sur les meilleures méthodes à suivre pour la levée des côtes, desirée par le gouvernement.

La marche que vous avez tracée à cet ouvrage dans votre lettre est très juste, et en contient les veritables principes; permettez moi de les étendre seulement, en y appliquant quelques considérations plus détaillées.

Pour faire cette levée avec toute l'exactitude possible, la marche à suivre seroit la suivante:

De mesurer par toute l'étendue des côtes avec un cercle répétiteur à deux lunettes, d'un pied de diamètre (ou à son défaut, avec un theodolite anglois de même diamètre au moins, et susceptible de multiplier les angles) une chaîne de triangles d'environ 60 à 100 mille pieds de côte, fondée sur deux ou plusieurs bases mesurées, avec les moyens d'exactitude connus. Toutes les observations et déterminations astro-

nomiques, que les circonstances permettront, ou qui peuvent être exigées, doivent être faites dans le cours de cet ouvrage, aux points convenables, tant pour déterminer les longitudes et latitudes des points, que les azimuths des côtés des triangles; se servant principalement du soleil et de l'étoile polaire pour les dernières déterminations et de signaux instantanés (p. ex. fusées volantes ou décharges d'armes à feu) données d'un point intermédiaire entre deux observateurs. On doit déterminer en même tems autant de points secondaires, et même autant de simples directions, qu'il sera possible, sans entraver le but principal. Cette mesure déterminerait, ainsi que vous l'avez observé, les fanaux, villes, villages, et autres points principaux des côtes, avec un nombre suffisant de signaux, érigés dans les lieux convenables pour la continuation des levées au détail. Les résultats seraient portés, d' après les différences des méridiens et parallèles, calculées pour le sphéroide terrestre, sur des grands papiers divisés en planches, d' après la convenance, accompagnés d'un tableau des longitudes, latitudes, distances, et azimuths.

Il serait avantageux de réunir toujours deux observateurs et une personne entendue pour signaler, &c.: il faut les subordonner, pour éviter les retards possibles d'une différence d'opinion sur les opérations. Il serait utile de former un centre pour tout l'ouvrage, sous un homme qui réunirait aux connaissances mathématiques celles de la géographie du pays ; chez lui seraient les calculs et la réduction de la grande mesure, la distribution, vérification, et rassemblement des ouvrages de détail.

Les journaux doivent être tenus avec une telle clarté que les observateurs, après leur retour, puissent les donner à toute autre personne entendue en tels ouvrages, pour en tirer les résultats. Ils doivent être in folio, et l'opposée de chaque page d' observation entièrement destinée aux remarques, dessins, descriptions des stations, même notice du tems, et autres. Une bonne methode de signalisation est très

importante pour la vision distincte et certaine, et par conséquent pour l'exactitude et l'économie du tems.

Les signaux de la chaîne de triangles doivent être des pyramides triangulaires équilaterales de 10 a 30 pieds de haut, à base proportionnée selon l'exigence des localités, formés de trois sapins fixés en terre et réunis au haut, surmontés d'une forte perche, portant une boule de poterie, avec un fort bon vernis jaune, d'un pied de diamètre, soit de toute autre matière qui formerait un point réfléchissant, ou bien d'une sphère de $1\frac{1}{2}$ à 2 pieds de diamètre, formée de cercles de barils, recouverte de toile blanche ou noire, selon que leur projection relativement à l'observateur tombe sur des objets terrestres, ou bien dans l'air ou la mer. Pour les signaux de nuit, des lampes d'Argand, à grandes mèches, de six pouces et même plus, de diamètre suivant les distances, peuvent être fixées sur ces signaux. Dans les basses terres ou les marais, les signaux élevés seraient indispensables. Au centre de la pyramide, pourrait être placé un appareil, d'un transport facile, pour supporter les instruments et les observateurs séparément. De cette manière, on pourrait observer avec une stabilité suffisante sur les terrains marécageux ; surtout si l'on doit se servir du cercle répétiteur à deux lunettes.

Dans les bois, les signaux peuvent être érigés sur quelque point un peu plus élevé, ou unis à des arbres d'une hauteur prédominante. Ils pourraient être arrangés de manière qu' un observateur pût monter dessus, pour prendre les angles avec un instrument à reflexion, supposé que leur mesure ne pût être suppléée par celle des autres angles du triangle, avec le grand instrument.

Les géomètres chargés de la levée du détail, auxquels les planches et tableaux susmentionés seraient distribués, doivent baser sur ces points donnés, pour faire tous les remplissages qui peuvent être desirés, soit avec de petits théodolites, la planchette, la boussole, le sextant, &c. suivant la convenance des localités et les moyens dont ils pourront disposer. Il pourrait être réservé des déterminations moins es-

sentielles, qui ne leur seraient pas communiquées pour servir ensuite à vérifier leur ouvrage.

Les sondes seraient levées par un petit bâtiment (p. ex. un *pilot boat)* avec un observateur à bord, suivant et secondant le géomètre levant les côtes. Il devroit être accompagné de deux chaloupes, pour la convenance des observateurs, pour servir de signaux, *&c.* Le bâtiment s'arrêtant chaque fois qu'il changerait de direction ou prendrait quelque sonde remarquable, l'observateur à bord mesurerait avec un sextant l'angle entre la station de l'observateur et la côte, (auquel il donne un signal) et quelqu' autre point convenable; en même tems l'angle entre le bâtiment et quelque point convenable, doit être observé sur la côte. La route du bâtiment ainsi levée, indépendamment des déterminations de loc et boussole, qui seraient néanmoins faites, découvrirait les courants (s'il y en a) par leur difference.

La levée nautique serait par là évitée, ou en cas de besoin substituée, lorsque celle aux côtes ne pourrait avoir lieu, suivant la convenance, et pourrait toujours être basée sur cette dernière. Il conviendrait que ces géomètres fussent secondés par un pilote, ou à son défaut par une autre personne connaissant bien les côtes, pour leur faire connaitre les objets remarquables, les noms, *&c.*

Dans ces levées, le problême des trois points, dont vous avez fait mention, trouverait souvent son application, mais étant sujet à une erreur d'autant plus grande, (en supposant quelque erreur d'observation ailleurs sans conséquence) que le point à trouver s'approche plus du cercle qui passe par les trois points donnés, au quel cas il devient indéterminé, il ne peut être donné en instruction generale. L'observateur doit donc, avant de s'y fier, s'assurer parfaitement que, dans le cas où il se trouve, l'usage lui en convient.

Le lieu d'un observateur peut aussi être déterminé par une seule ligne, donnée en longueur et direction avec le méridien, sous les latitudes données, par la mesure de leur angle au point cherché, et d'un azimuth.

Pour toute détermination d'azimuth, il faut faire usage des observations du soleil et des étoiles, surtout de l'étoile polaire. Il serait avantageux pour les géomètres occupés au détail de faire une instruction des problêmes de cette espèce, qui montrât dans quel cas l'application de l'un ou de l' autre est favorable ou non, avec les meilleures méthodes d'en faire l'observation, le calcul, la construction, &c. le tout adapté au mode de levée qui sera mis en usage, peut être même on pourrait y joindre des tables.

Un tel systême d'opération étant susceptible de tous les degrés d'exactitude qu'on peut désirer, (dans les grands triangles elle peut être à $\frac{1}{10000}$) et portant avec lui sa propre vérification, donnerait des résultats à tout usage, et permettrait de travailler hardiment dans les levées de détail, par les occasions fréquentes de vérifier l'ouvrage ; cette partie tire sans cela toujours beaucoup plus en longueur qu'on ne pense d'abord. Plus le systême adopté s'approchera de celui que j'indique, plus il donnera d'exactitude et d'utilité dans les résultats.

Si un tel plan d'opération était regardé comme d'une exécution trop entravée par les localités, il faudrait y substituer le suivant, qui serait :

De suppléer la mesure triangulaire par les déterminations de longitude et latitude, avec des chronomètres et des sextants ou cercles de reflexion, qui doivent dans ces cas être de première qualité, et les chronomètres toujours. 2. Une série de points et signaux, systêmatiquement placés et distribués, doivent par là être déterminés, de même que les triangles de la méthode precedente ; des déterminations d'azimuths et même des lignes mesurées et des triangles levés avec les instruments à reflexion, devraient y être joints, lorsque l'occasion s'en présenterait, tant pour multiplier le nombre des points déterminés que pour vérifier les déterminations astronomiques, l'une par l'autre mutuellement. Pour suppléer au défaut de pouvoir observer la double hauteur méridienne du soleil en été, il faudrait se servir d'étoiles bien déterminées, surtout de l'étoile polaire.

Aux endroits convenables et d' un interêt majeur, il faudrait, par la multiplication et variation des observations, suppléer par la jonction des observations astronomiques aux mesures des triangles mentionnés dans le systême précédent.

Cette méthode, quoiqu' elle ne soit pas susceptible de toute l'exactitude de la précédente, est cependant exempte du défaut d'accumulation d'erreurs, parceque les déterminations sont indépendantes les unes des autres (on peut estimer les latitudes à 10″ de degré, et les longitudes par chronomètres à 2″ de temps exact.) Son inconvénient est de ne pas donner avec la même facilité et précision des déterminations de distance en longueur pour l'usage des levées de détail, desavantage qui est en proportion de la grandeur de l'échelle dans laquelle elles sont desirées. Ce qui a été dit sur la vérification des différences de longitudes par signaux instantanés, sur les signaux, les divers journaux, et les personnes requises, est absolument le même pour cette méthode. Les levées de détail pourraient y être faites de la même manière que dans le systême précédent, en disposant proprement pour ces usages, les triangles, et autres mesures mentionnées.

Les détails pourraient aussi être levés par une extension de cette dernière méthode jusqu' au détail, et alternativement même à une levée nautique. Mais alors, pour ne rien omettre, il faudrait faire tous les calculs de suite. Après les observations, on perdrait l'avantage de pouvoir les vérifier et tirer parti d'observations subséquentes. Les mêmes personnes employées aux déterminations les plus essentielles, seraient ainsi chargées des menus détails, ou en dépendraient dans leur marche, étant obligés de diriger ou préparer et fournir l'ouvrage des géomètres occupés du détail, la marche systêmatique n'existerait donc plus.

La dépense de l'une et de l'autre de ces deux méthodes peut être regardée comme la même. Ce que l'une coûte en instruments à mesurer les angles et transports de terre, l'autre le coûte en chronomètres et louage de bâtimens.

L'économie du tems est décidée: 1° Par la saison plus ou

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moins favorable aux observations astronomiques, dont la levée chronométrique à plus besoin que celle des triangles, qui peuvent être mesurés souvent, quand les observations astronomiques ne peuvent avoir lieu; 2° Du degré d'exactitude exigé de la mesure des triangles, qui demandent plus de tems à proportion que les observateurs doivent être scrupuleux; 3° Du plus ou moins d'entraves que les localités mettent à l'une ou l'autre méthode.

La différente nature des côtes et le différent nombre d'objets à lever (comme isles, bayes, &c.) sur une même étendue de côtes extérieures, pourrait, peut-être, faire préférer, pour une partie de l'ouvrage, la levée suivant une méthode semblable à la première, et pour une autre la levée chronométrique, et même la nautique. Pour bien juger de cela, il faut avoir des connoissances locales, qui me manquent jusqu' à present.

Excusez, Monsieur, ces détails et la longueur de cette lettre; mais neuf encore dans ce pays, je n'ai pu parler qu'en principe, et discuter, sans décider: la connaissance des vûes particulières qui pourraient entrer en considération, des moyens scientifiques et des personnes dont on peut disposer, ainsi que des obstacles qui peuvent se rencontrer, me manque; de là dépend la décision de la préférence pour l'une ou l'autre des deux méthodes, qui sont, à mon avis, les plus exactes, et les plus convenables aux vûes principales du gouvernement.

J'ai l'honneur d'être,

Avec le plus parfait respect,

Votre très dévoué serviteur,

F. R. HASSLER.

M. Gallatin.

Plan for putting into operation the Survey of the Coast of the United States.

In my general plan of operation for the survey, I mentioned, that the establishment of two observatories would be necessary; and I thought it proper to procure the instruments, destined for them, of such a quality and size, as to be suitable for a permanent national institution. For this purpose, it would now be necessary to add only a mural circle and a zenith sector, which, however desirable, I did not venture to order, as their absolute necessity, in connexion with the survey of the coast, was not so obvious as that of the instruments procured.

These observatories form the fixed points, to which the survey, and particularly the naval part of it, is referred. The selection of proper places, the erection of the buildings, and the setting up of the instruments, will require some time. It would therefore be desirable to begin with this part of the general observation as soon as possible.

As they will be permanent scientific establishments, it will be proper to decide whether the expense of their erection shall be comprehended under those of the survey, or be considered as separate.

It will also be necessary to decide, where they shall be erected. To procure the greatest advantage for the survey, their positions should be as far north-east and south-west as the very favourable position of the United States admits. The same location affords also the greatest scientific advantages. Supposing one in the District of Maine and the other in Lower Louisiana, nearly every celestial phenomenon observable from the tropic to the arctic circle, and within about two hundred degrees of difference of longitude, could be observed at one or other of them. The comparison of their distance and position, as determined astronomically and geodesically, would offer the most rigorous proof of the sur-

vey. The observations made in them could be compared with each other, so as to render them independent of foreign observatories. Still, various considerations might occasion and favour the desire of placing one of these observatories in the city of Washington, as observatories are placed in the principal capitals of Europe, as a national object, a scientific ornament, and a means of nourishing an interest for science in general.

This observatory would then be the most proper place of deposit for the standards of weights and measures, which make part of the collection of instruments.

The observatory will require a constant observer; the duties of whom are evident from the nature of the instruments and the object of the establishment, viz. to make observations of every phenomenon leading to the determination of time and longitude. When the position of such an observatory shall be determined, I will have the honour of submitting a plan of construction adapted to the object and the locality.

The wooden stands for the instruments, the boxes for the bars to measure the base lines, and the tin cases to make the pyrometrical experiments with, being objects of bulk and inconvenient transportation, I preferred having them made in this country. Their construction is necessary to fit the instruments for actual use. As soon as this is done, I should proceed to standard the bars for measuring the bases, and to make the pyrometric experiments upon them. It would be very desirable that I should be authorised to make an expenditure of about eight hundred dollars for these objects, as well as for signal spheres, and lamps for night signals, which I found it also better to have made in this country.

All these preliminary objects could be attended to this winter, so as to enable me to begin, next spring, the first part of the survey itself, viz. the reconnoitering of a part of the coast, in order to project a part of the triangles best suit-

ed for accuracy, as well as approaching nearest to the figure of the coast, and to find a proper place for a base line to ground them upon.

In this operation, I should wish to be accompanied by a man acquainted with the part of the country I shall have to go through, and to be allowed an expenditure, for the transportation of the small instruments, the erection of temporary signals, &c.

Thus prepared, it would be possible to make the actual measurement of one base line in the latter part of the summer or in the fall of the present year. During this time, the building of at least one of the observatories should be completed. The instruments destined for it could then be put up during the winter, and the adjustment of those intended for the survey itself could be made with the necessary attention and minuteness.

The work of the principal survey will be to form a chain of triangles, with sides of about thirty miles in length, along the whole extent of the coast, so as to join the distant parts by the shortest and most accurate lines possible, and to determine the azimuths of the sides of the triangles, and the latitudes and longitudes of their angular points.

Within these, a series of triangles, with sides of about ten miles, will be formed to join them, part of which it will sometimes be possible to carry on simultaneously with the large ones. The object of these will be to furnish an ample number of determined points, to which the survey may be referred, in all its details.

It will be necessary to furnish the chief operator with the following assistance:

1. Two officers of the corps of engineers, well informed in mathematics, and with so much knowledge of the practical operations, as will enable them to make the secondary observations, and to keep the journal of them correctly.

2. Twelve men of the corps of engineers, most of them artificers, with a sergeant and corporal.

3. One baggage wagon, with the necessary horses, and a driver.

4. Tents and other field utensils, sufficient to accommodate the persons employed, and to shelter the instruments. It will be necessary to construct the tents for the instruments particularly for the purpose.

5. It would be convenient, and in many cases important, that a few cadets should be added, who, by following the work, would prepare themselves to take the station of the officers, when they would be employed in operating by themselves, as will be mentioned hereafter.

The duty of one of the officers will be,—to act as assistant observer, captain of the men employed, and purser for all expenditures relating to the transportation of instruments, the construction and erection of signals, and other similar objects. For this purpose, it will be necessary to make a yearly appropriation of about two thousand dollars, of which he will have to keep an account. I suppose that the support of men and horses will be comprehended under the military expenditures.

The duty of the second officer will be,—that of a lieutenant of the soldiers, and of secretary to the observers. This last office is necessary for the observations. Without it, it would be often impossible to execute them within the absolutely necessary limit of time.

The wagon will serve to transport the baggage, provisions, tents, signals, tools, and such of the instruments as will bear this mode of transportation.

The employment of the men will be,—to carry the principal instruments from station to station, to erect signals, to prepare the stations for observation, clearing the ways, and various similar works, which will occur constantly in the course of the survey.

This mode of proceeding will make the actual expenses of the survey the smallest possible, as the requisite aid may easily be obtained from the army, without interrupting its

service. It will have the advantage of preparing officers in an essential part of their employment, and of giving them a knowledge of the localities of the country, by which they may become particularly useful in future.

The survey cannot be carried into its details, until such a portion of the above work shall be executed and actually calculated, as will serve to occupy two or three detail surveyors, in a certain district.

The same is to be observed with respect to the nautical survey, which is to extend from the coast as far as any object important to navigation may occur. It will be most proper to use, in these parts of the work, well informed officers brought up at the military academy, and naval officers.

It was the intention of Mr. Gallatin to divide the whole work into two parts. If that should be the wish now, two corps of surveyors, as described above, would be required.

As the general chain of great triangles must, however, form one single system, it may be found proper not to make this division, until a part of these are done, and when the secondary triangles, being more numerous, will require an increase of the number of observers.

Such distributions of the work may be advantageously made, as the principal work is proceeding; when it might be divided into such a number as the localities would indicate. Thus, for instance, the coast of Louisiana being, by its geographical position, separated from the other parts of the coast of the United States, would, of itself, form such a subdivision.

Robert Patterson, Esq. Director of the Mint in Philadelphia, has, from the beginning, been appointed general superintendant of this work. In him the correspondence, and general communications relative to it, have been made to centre.

This part of the arrangement is therefore considered as fixed, independently of the present plan; which is intended merely to comprehend the ways and means for putting the survey itself into operation.

According to the directions of Mr. Gallatin, the collection of instruments is made sufficient to furnish, temporarily, the necessary instruments for a determination of boundary lines. If, therefore, any such work is now in contemplation, the instruments for it may be supplied from the collection.

F. R. HASSLER.

Washington, 5th January, 1816.

On the 15th of May, 1816, a communication was made to the government, on the measures necessary to be then taken, in order to put into immediate operation such portions of the work as could be undertaken during that season. As this communication did not differ, in any essential particular, from the above, it has not been thought necessary to insert it here.

A Catalogue of the Instruments and Books collected for the Survey of the Coast.

It may be proper to insert this catalogue in these papers, both for the convenience of reference, and as an account of the means by which the work of the survey was to be executed.

The instruments were the following:

1. One theodolite, of two feet diameter, made by Mr. Troughton.

2. Two double repeating theodolites, of one foot diameter, with a complete vertical circle by the same.

3. Two double repeating circles, of eighteen inches diameter, with two telescopes, made by the same.

4. Four double repeating reflecting circles, of ten inches diameter, with stands and artificial mercury horizons, and spirit levels for measuring small angles of elevation, made by the same.

5. Two reflecting circles exactly like the former, without stands or levels, by the same.

6. Two artificial horizons of mercury, with a glass cover.

7. Two artificial horizons, of dark plane glasses, of eight inches diameter, with ground spirit levels.

8. Two common surveying theodolites, of nine inches diameter.

9. Two compasses, with needles one foot long, with centre work and spirit levels, made by Thomas Jones.

10. Two alhidades for plane tables, with transit telescopes, made by Thomas Jones.

11. Two plane tables, suited to these instruments.

12. Two sets of apparatus for measuring base lines by a peculiar arrangement: each set consisting of the following parts, viz. four bars of iron, intended to be made the length of two metres; various screw works and a number of rollers for the motion of these bars, and of the boxes intended to receive them; a sector with a spirit level; a directing telescope; four thermometers; and three stands, with motion works, and microscopes with two different foci. Made by Mr. Troughton.

13. One standard English brass scale, of eighty-two inches in length, divided on silver into tenths of inches, with a microscope, and an arrangement for the comparison and construction of other scales. Made by Mr. Troughton.

14. One iron toise, standarded by Lenoir in Paris, and compared with the toise of Peru at the observatory, by Messrs. Arrago and Bouvard.

15. One brass metre, standarded by Lenoir, and compared with the iron metre at the observatory of Paris, by the same gentlemen.

16. A certificate of these two comparisons, signed and sealed by these gentlemen.

17. One iron metre, standarded by Lenoir.

18. One iron tool for filing off bars, perpendicularly to their length, by a rotatory motion.

19. One iron plane.

20. One strong very fine balance, with English weights, from 10,000 grains to decimals of grains, standarded by Mr. Troughton.

21. Two subdivided kilograms, in the form of parallelepipedons, standarded by Fortin in Paris, who was employed by the Committee of Weights and Measures in making the originals.

22. Two standard litres, with covers of ground plate glass, standarded by Fortin.

23. Two transit instruments for observatories, with five feet telescopes, made by Mr. Troughton.

24. Two astronomical clocks for the observatories, with mercurial compensation pendulums, made by William Hardy in London, on the same plan as that of the Greenwich observatory.

25. Two box chronometers, going one day, with silver dials, and corrections for short and long vibrations, made by the same.

26. One box chronometer, going two days, by Mr. Brockbank.

27. Two box chronometers, going only one day, by the same.

28. Two silver pocket chronometers, by the same.

29. One box chronometer, by Grimaldi and Johnson.

30. Two time pieces, shewing the three hundredth part of a second by a hand attached to the balance, made by Mr. Hardy.

31. One six feet achromatic telescope of Dollond, with a four and a half inch aperture, one terrestial and six astronomical eyepieces, a finder, the tube in three parts screwed together, and a mahogany stand in two parts.

32. One five feet achromatic telescope, with a four inch aperture, one terrestrial and six astronomical eye tubes, brass

shifting equatorial motion, mahogany folding stand, steadying rods, and a lanthorn illumination, by means of a small reflector in the centre ; also by Dollond.

33. One five feet achromatic telescope of Tully, with a four inch aperture, the tube in two parts, one terrestrial and four astronomical eyepieces, level, finder, steadying rods, folding mahogany stand, &c.

34. One achromatic telescope of Tully, four feet eight inches in length, with a three and a half inch aperture, tube in two parts, two terrestrial and four astronomical eyepieces, mahogany folding stand, &c.

35. One three and a half feet achromatic telescope, with a three inch aperture, one terrestrial and six astronomical eyepieces, simple brass tube without stand or finder, by Dollond.

36. One three and a half feet achromatic telescope, with one astronomical and two terrestrial eyepieces, three inch aperture, brass stand, and steadying rods, by Troughton.

37. Three double wire micrometers, by Dollond, with changes of eyeglasses and prisms for high altitudes, to be placed before the eyepieces, two of them fitting the telescopes, No. 31 and 32, and the third the four other telescopes.

38. One top joint and socket for a telescope, on three legs of wood, to fit any telescope, for easy transportation.

39. Six mountain barometers, with brass mountings, by Mr. Troughton. N. B. These were brought without mercury in them, for greater security against breaking on the voyage.

40. Two large thermometers, extending to the boiling point, with Fahrenheit's and Reaumur's scale, intended for the observatory, by Mr. Troughton.

41. Two thermometers, on boxwood scales, brass shelter to the balls, also for the observatory, by Mr. Troughton.

42. Four detached spirit levels, of two different sizes.

43. Two sets of magnetic bars, one containing two, the other four bars.

44. One dynameter, by Dollond.

45. Two beam compasses, with short and long rods, and a double set of points, and one set to work upon brass, by Fidler.

46. Three proportional compasses, with perpendicular legs, for reduction and for constructing maps, by Fidler.

47. Two steel rules, five feet long and four inches broad, and four steel triangles of two sizes, to use with them by Fidler.

48. Various duplicate parts, to replace accidental loss or breakage; as turnscrews, metal wire, spirit level tubes filled, dark glasses, magnifiers, barometer tubes, &c.

49. The books consist of the best and most recent works on astronomy and geodesy, particularly useful for the instruction of the young officers intended to be employed in the work,—the newest astronomical and logarithmic tables of different kinds,—catalogues of the fixed stars, and celestial atlasses,—some other works of interest for the observatory, —the French Connaissance des Tems for several years,—in the whole forty-five works, of many of which duplicates were provided.

Comparison of the French and English Standard Measures of Length, and Regulation of the Bars for the Base Line Apparatus.

The necessity of having a standard measure of length, as accurate and as authentic as possible, for the measurement of the base lines, is sufficiently evident to shew the propriety of all the care which was taken to attain this object.

The two measures of length which have been the most scientifically ascertained and compared, are the French and English.

They are essentially different in their principle, and of

different metals, which circumstance has always presented difficulties in their comparison.

The English standard is a *brass scale*, divided into inches and tenths of inches. Upon this, the mean of all the possible measurements of any distance is considered as the proper standard value of that distance, the yard and the foot measured in this manner being equally legal standards, though probably the yard was originally intended as such. The different scales are of different ages and accuracy; having been successively improved by various artists, by making scales from the mean lengths of various distances, taken according to convenience, upon the scale from which the new standard was copied. Upon this subject, Sir George Shuckburgh Evelin's Account of the Comparison of Measures may be consulted.—Philosophical Transactions of London, 1798.

The French standard consists in a *certain determined unit of length in iron*, given by a bar cut off to the given length, either a toise, as formerly, or, as at present, a metre; the iron toises of Peru being the only authentic original to which all toises are referred, and the metres of the Committee of Weights and Measures the authentic originals of the metres. Of their ratio and the mutual comparison of their measures, the "Base du Systême Métrique" gives a sufficient account.

The standard temperature of the English scale is 62° of Fahrenheit's thermometer; that of the French metre 32° of the same scale; and the metre having been compared with the toise at this temperature, it has also been adopted for the toise, which was formerly referred to 16° of Reaumur's scale.

He who has ever attempted to copy any absolute measured length, with the accuracy necessary to form a standard, must have soon discovered what great minuteness, and care in the choice of means, are required for this purpose. Beam compasses and similar means will soon be found inadmissible. The successive transfer of a measure from a

scale is far less satisfactory than the successive mechanical addition of a number of copies made from a standard unit, and compared to the same, or any other, by proper means. This conviction, derived from experience and a careful comparison of the modes of proceeding used in the late works of this nature in Europe, decided me to adopt, for the unit measure of the bars intended for the base, the combination of four iron bars, each of two metres in length.

I had one more decisive reason for this choice, viz. that I had at my disposition one of the metres standarded by the Committee of Weights and Measures in Paris, in 1799, which being of the same authenticity, in all respects, with any of these measures in the possession of the respective governments, and with the platina metre of Paris, places the accuracy of my unit measure beyond all possible doubt. The comparison made between the different standards, this being among the number, reduces any multiple length of my determinations to any standard desired, by an easy numerical calculation.

This comparison of the different standards, and the standarding of the bars for the base line, I executed in the months of February and March, 1817; but I intended to repeat all the comparisons again, before the measurement of the first base line with the bars. I had likewise intended to compare the standard metrical and troy weights, of which I had a full and authentic collection, by the fine balances placed in the collection for that purpose, and by another founded on hydrostatic principles, invented by my friend and teacher, M. Tralles. All these it was not possible for me to effect: I will however here record what I have been able to do in this respect.

I will first give an account of the particular standards which I have compared, and of their origin, so that a judgment may be formed of their authenticity. I shall also state the means employed in their comparison, and for the standarding of my bars,—to shew the degree of reliance which may be placed in my results.

The standards were the following:—

1. An iron metre standarded at Paris, in 1799, by the Committee of Weights and Measures, composed of members of the National Institute, and of deputies from other countries. Its breadth is 1.13 inches, its thickness 0.36 inches, English measure. My friend, Mr. J. G. Tralles, now member of the Academy of Sciences of Berlin, was at that time the deputy of the Helvetic Republic for this purpose; and, as may be seen in the account of the operations of this Committee, he was the foreign member directing the construction and comparison of the measures of length. He had one metre constructed for himself and one for me, at the same time with all the others, and subjected in all respects to the same processes and comparisons. In the ultimate distribution, it is known, that they were taken indiscriminately, and considered equally authentic, this metre being one taken by M. Tralles. He was so kind as to give me, at the same time, a standard *kilogramme*, constructed in the same manner, under the direction of Mr. Van Swinden. These original standards, both of length, measure, and weight, bear the stamp of the Committee, viz. a section of the elliptic earth, of which one quadrant is clear, with the number 10,000,000 inside of the arc; the other three quadrants being shaded.

2. One iron toise, with its matrix, in which it fits exactly, forming together a bar of three inches broad and half an inch thick, French measure. It is of careful execution, and presents the form seen at Plate IX. fig. 11. It was made by *Canivet, à la sphère, à Paris*, which is also engraved upon it, as also the notice, *Toise de France, etalonée le* 16^{me} 8^{bre}, 1768, *à la temperature de* 16° *du Thermomètre de M. de Réaumur*. A line is drawn along the back of the toise, and from a perpendicular, crossing this line near one of its extremities, to a point taken near the other extremity, is engraved, *La double longueur du Pendule sous l'Equateur*. A point is marked between the other two at the simple length of the pendulum. Having been in Paris, in 1796, shortly after the death of M. Dionis du Séjour, I bought this toise

from his heirs. M. Lenoir, the artist who made the metres of the Committee, considered this standard, and that of M. Lenoir, well known from the Base Metrique, to be the most authentic of the kind in private hands. About the time stated for the standarding of this toise, the Academy of Sciences of Paris discussed the propriety of establishing, as a natural standard, the double length of the pendulum under the equator. M. Du Séjour being then a member of that Academy, and interested in the subject from his situation, this toise probably had reference to their views, which were afterwards directed to the metric system.

3. Two copies of the toises of Lalande, which were compared in England with Bird's scale, in 1765. The originals were lent to me by M. Lalande, in 1793. M. Tralles and I made two exact copies of each. The present are two of those copies: they are marked A. and B. like their originals.

The standards hitherto mentioned I brought with me to this country, in 1805. They are now deposited with the American Philosophical Society in Philadelphia; together with various works connected with the subject of a General Standard of Weights and Measures.*

4. A brass metre, of the same breadth as the iron metre above and half as thick, standarded by Lenoir in Paris, and compared by Messrs. Arrago and Bouvard with the iron metre, at the observatory, the 16th of March, 1813, as stated, No. 16 of the catalogue of instruments procured for the survey of the coast. M. Lenoir, who was employed by the Committee of Weights and Measures for the construction of the standard, had made for himself, at that time, a brass metre, which underwent all the comparisons at the standard temperature at the same time with all the iron and the platina metres. The present is a copy of this metre, respecting which the certificate mentions,—En applicant à nos mesures une correction dependante de l'inegalité de dilatation des deux metaux, il nous a semblé, qu' à zero du ther-

* See p. xliii., Vol. VI. Old Series.

momètre, le mètre en cuivre serait plus court que l'etalon en fer de nos archives de $\frac{1}{100}$me de millimetre.

5. An iron toise standarded by Lenoir, No. 18 of the catalogue of instruments. It is an inch and three quarters broad, and one third of an inch thick. The comparison of it by Messrs. Arrago and Bouvard, made at the same time with that of the metre above, says that it was found exactly equal to the toise from Peru in the archives of the observatory.

6. One iron metre standarded by Lenoir in Paris, but not compared at the observatory of Paris; being No. 18 of the catalogue. It is exactly of the same breadth and thickness as the metres of the Committee.

7. An iron bar, similar to the metre just mentioned, and intended to be brought to the metre length, in the course of these operations.

8. The brass standard scale, No. 13 of the catalogue, by Mr. Troughton. It contains 82 inches, divided into tenths, upon a strip of silver extending over its whole length. It is three inches broad, and half an inch in thickness. It bears the arms of the United States, and the name, *Troughton, London*, 1813.

To it belongs an apparatus for comparing measures by two compound microscopes, sliding on a rule and placed parallel to the scale of the same breadth and thickness. One of the microscopes has two fixed wires crossing under 30°, the other a micrometer with similar wires, pointing out distinctly the ten thousandth part of an inch. This apparatus has been described in Nicholson's Journal, and other works. A proper apparatus, with a Hindley's tracing tool, was added, to which the micrometer microscope is adapted, for the purpose of constructing other scales from this.

The scale was divided with that extreme care and accuracy for whch Mr. Troughton is so justly praised. It contains the double length of the principal part of his scale, of which an account has been given in Sir George Shuckburgh Evelyn's paper referred to above. Mr. Troughton first compared the

different portions with one another, for which comparison and the subsequent division, he had constructed a proper apparatus. He thus formed a table of errors for his scale, in the manner described in his method of dividing, (Phil. Trans. of 1809) and then laid off the new scale, correcting each point according to the indication of the table.

The French standards were all compared with this scale of Mr. Troughton, by means of the apparatus described, and by methods which will be mentioned hereafter.

My particular method of standarding the double metre bars required another apparatus, which I had constructed for the purpose.

It may be said to be impossible to cut a bar perpendicularly to its length, by hand, with the accuracy required. The tool in question is intended for this purpose. The following are its principal parts:—

A plate of cast iron, about eight inches broad and two feet and a half long, exactly even and smooth, is adjusted by screws from below, upon a strong iron frame, at one end of which two pieces direct, in a perpendicular slide, the socket piece, which receives the axis of a circular file, of about three inches in diameter, to which the above plate is adjusted, so as to make the bar laid upon this plate, and presented to the file, exactly perpendicular to it. A strong iron bar is made to slide over the whole length of the plate, by means of two horizontal screws. The bar to be filed being laid upon the plate, and against this bar, a trial of filing, in two inverted positions, will show any defect of adjustment double. The adjustment must be made accordingly, and the surface of the cut will be perfectly even. There is a change of files of different fineness, and for the last, a turkey stone, which will take off all the marks of the file, and grind the surface smooth.

When only one bar is to be standarded, this tool must be used throughout with its different files, and the turkey stone last. But as I had four equal bars to standard at once, and could make the planes of their ends more perfect in conse-

quence of the great surface they presented when joined together, I proceeded somewhat differently for the last finishing.

The bars were guaged, as nearly as the workman in London could do it, to the breadth and thickness of the metres of the Committee, and made seven feet four inches long. The double metre being only about six feet seven inches, there were nine inches to be cut off, which allowed me to make choice of the best parts of the bars for the cuts, and to avoid the parts near the ends, which are never equally well guaged, because the tools, which they are worked with, lose there their steady support, and fall off. The pieces so cut off were besides wanted for making the butting pieces for these bars and the metres in the comparisons, and for the final adjustment of these bars, as will be shown hereafter. The bars were lettered A, B, C, D, for the convenience of registering them. After their first cutting, there was enough left in length for the perpendicular filing. To bring them as nearly as possible to an equal breadth and thickness throughout, so as to present for the final adjustment one entire connected mass, they were all four laid close to each other upon a strong work bench, and pressed together by wedges. In this position, they presented, by the sum of their breadths, a surface four inches and a half broad, and by that of their thicknesses, one inch and a half. They were then filed together, with one of the circular three inch files of the above tool, varying their situation successively on both sides and in all positions. By this process they were brought to present, in all the combinations, an equal breadth and thickness throughout, and to lie together like one mass.

Having thus fitted the bars for lying accurately against the filing tool, they were filed down nearly to their proper length. A proper arrangement was made to extend the horizontal plane of the iron plate, so as to support the whole of the bar. Two of the pieces cut from the ends, one five, the other seven inches long, were adjusted, by the filing tool,

like the bars themselves, and rubbed with emery and oil, to serve as butt ends, for the final adjustment of the bars.

To execute this, the iron plate of the filing tool was fitted tight in the end of a plank, so as to continue its plane over the whole of it, to a greater length than the bars, and the plank was then planed, so as to form an exact continuation of the plane of the iron plate. Upon this plane the four bars were laid along side of each other, pressed together between brass pins and wooden wedges, and held down by wooden clamps. The ends upon the plank were butted by a straight piece of wood. The ends on the iron plate were rubbed with the seven inch long butting piece, with emery and oil; changing their relative position occasionally, until their ends presented, in all positions, one even, plane, and smooth surface, upon which the rubbing piece touched equally in all places, so as to present with them all one even, sharp, and straight line at their upper surface.

They were then all turned end for end, and made to fit against the five inch iron butting piece, so as to present again one even and sharp line, to which they were of course perpendicular. In this position, they were again fastened as before, and rubbed again with the seven inch butting piece, changing their relative position, until they presented, at these ends also, one uniform regular surface and sharp top line. The two iron metres of the Committee and Lenoir were then laid upon them, and appeared to coincide with them in length. This was of course tried several times; wishing however to suffer them to be somewhat longer, because the cooling down of the metal, which is always more or less heated by the working, will always shorten them somewhat. Indeed I have observed that the copies of measures made in this way are generally shorter than their originals, from this circumstance; their comparison being probably made too soon after the work, and before the metal is actually cooled down to the temperature of the original with which they are compared.

For the actual comparison of the metres and these bars, it was necessary to place them on the work bench, on which the above described comparator and English brass scale were, at the exact height, which would bring their upper surface, without parallax, to the foci of the microscopes, which were of course adjusted for the divisions of the scale. The influence of unequally supporting the standard bars, by merely laying something under them at different places, being great, I caused pine rules to be made, of sufficient breadth and length, and of the exact thickness required for each standard. Upon these each standard was laid, together with its proper butting pieces, when under comparison.

As it is wholly inadmissible to take the edge of a bar as an object under the microscope for the purpose of comparison, because it never gives a good image, the shorter pieces cut from the bars, from two to four inches in length, were filed on the tool, in the manner of the butting pieces above described, brought to the exact thickness of the standard with which they were intended to be used, and then the butting faces of them rubbed against each other with emery and oil, upon the iron plate of the filing tool, constantly inverting their positions, until such a perfect contact was obtained, that the line formed by it was not so thick as one of the divisions of the scale.

These pieces were always laid against the ends of the standard under comparison, so that the junction appeared like a line drawn upon the standard, with which the cross wires of the micrometer were made to intersect. The microscopes were furnished with reflectors, formed of white paper placed in a position inclining forwards, between the microscopes and their supports. By these the light was reflected upon the scale, or the standards, in the direction of the division lines, as required for accurate reading.

To prevent the heat of my body from having any influence on the scale and apparatus, a large sheet of paper was nailed to the work bench near the microscopes, and I worked with gloves on.

From seven to twelve thermometers were laid constantly over the scale and the standards, and were read at proper intervals of time.

The work bench itself was about double the length of the scale. It was accurately adjusted before the work, and the scale was so placed with respect to the windows of the room, that the microscopes received their light from separate windows.

The bench was made of two planks three inches thick, placed at right angles to each other, so that a transverse section was in the form of the letter T. The top plank was about twelve inches broad, and the whole rested on six legs.

No fire was kept in the room while the comparisons were making; and for some time before, the windows were left open day and night, to keep the different parts of the room in an equal temperature, being that of the surrounding atmosphere.

For the comparisons intended to be made in one day, every thing was prepared the day before, and left in such a state as to require as little handling as possible. This was done, in order that the parts of the apparatus might acquire throughout an equal temperature.

All these precautions were necessary to obtain satisfactory results, as is well known to men in the practice of such operations.

The probable error in the microscopic readings may be considered as increasing with the number of these readings. Having four metres, and the scale being sufficient to take in two, I had the means of diminishing this error one half, by comparing two at a time, instead of one. An equation between the results then enabled me to obtain the value of each metre. This method had the advantage of removing every prejudice from the mind of the observer in regard to the readings, in as much as the combination of the different measures and the different influence of temperature occasioned a variation which completely precluded previous estimates.

To prepare for reading, the microscopes were placed over the decimals, which, on the scale, corresponded to the length of two metres, viz. 78″,7 or 78″,8 ; and this distance was taken from +1″ to 79″,8 ; which brought it equidistant from both ends of the scale. The microscopes were fixed to this distance upon the scale with the greatest care ; were then left for some time and were again verified. The scale was removed, and the two metres, with their supports, properly laid in its place, so as to bring the middle of their breadth under the faces of the microscopes. The middle contact was exactly made, the butting pieces laid to both ends, the coincidence of the end under the microscope with fixed wires effected, the middle contact again verified with a magnifying glass, the moveable wires of the micrometer microscope moved by the micrometer screw upon the image of the contact under its focus, and the value of the corresponding subdivisions read on the micrometer by its revolutions and subdivisions.

The longitudinal motion required to effect the contact cannot be communicated by the hand alone: the best mode of communicating this motion is by a few light strokes of a suitable piece of wood, applied carefully, and in such a manner as not to separate the different pieces by the counter-stroke.

The value of the micrometer parts was ascertained by repeated measurements of a decimal in different parts of the scale. From a mean of many such measurements, with the adjustment of the microscopes used for the metres, I found one decimal on the scale to be measured by one decimal and four units of the micrometer, or 0″,1 of the scale equal to 0″,1004 of the micrometer.

Lastly was to be determined, the individual value of the distance on the scale used in the comparison, in relation to the mean value of the same distance, resulting from its measurement taken on as many parts of the scale as were admissible, in order to give to the standards compared their

value in terms of the mean distance of the scale, according to the principle of the English standard. This was effected by about fifty measurements with an unaltered microscope, and gave the distance used, 79″,8—1″,0=78″,800172 of the mean value of the scale. To this distance all the values obtained in the metre comparisons were ultimately referred.

To shorten the mode of registering the results, the combination of the metres, and their position, the following notation was adopted :—

M^c	denotes	The iron metre of the Committee of Weights and Measures in Paris.
M^l		The iron metre of Lenoir.
M^b		The brass metre of Lenoir.
M^y		The iron bar which I intended to bring to the metre length.
M^{c+l}		The metre of the Committee and that of Lenoir added together,—all marks being upwards.
$M_{ɔ+ʅ}$		The same metres,—all marks being downwards.

In like manner, in the other combinations, the addition of the special marks at the top, always denotes the sum of the metres so indicated, and the inversion of these letters the inversion of those metres.

On the 15th of March, early in the morning, the eleven thermometers, which remained on the scale during the preceding night, were read; and after having assured myself that all was in good order, I observed the comparisons inserted in the following table :—

Standards compared.	Micrometric measurements.	Mean of the four results.	Correction of micrometer.	Final value of the mean.	Mean of thermometers. *Fahrenheit's Scale.*
M^{c+b}	78″,760400				30°,85
$M_{ɔ+q}$	78″,761150				
Ends changed to middle.		78″,760962	—0″,000244	78″,760718	
M^{c+b}	78″,760990				
$M_{ɔ+q}$	78″,761310				
M^{b+l}	78″,759030				
M_{q+l}	78″,760575				
Ends changed to middle.		78″,759777	—0″,000240	78″,759537	
M^{b+l}	78″,759200				
M_{q+l}	78″,760303				
M^{c+l}	78″,760415				
$M_{ɔ+l}$	78″,760450				
Ends changed to middle.		78″,760472	—0″,000242	78″,760230	
M^{c+l}	78″,760475				
$M_{ɔ+l}$	78″,760550				34°,1

About half past eleven, the four double metre bars were successively put under comparison for the first trial of their length, and found, by one single measurement only for each, as follows:—

Bar A	78″,761500	—0″,000246	78″,761254	
B	78″,762275	—0″,000290	78″,761985	
C	78″,761450	—0″,000245	78″,761205	
D	78″,760900	—0″,000240	78″,760660	
				36°,1
Sum	315″,046125	—0″,001021	315″,045104	

The sum of the four double metre bars appearing still too great, the bar B, which gave a result above the others, was rubbed somewhat more in the manner above stated, though single, some of the butting pieces being laid on the side to support the plane.

The micrometer microscope, in the foregoing comparison, was read by addition, or from 78″,7 onwards. On the 17th of March, it was turned one half revolution horizontally, so as to read by subtraction, or from 78″,8 backwards, to compensate any possible influence of the micrometer. The micrometer values were verified again in this position, and found as before; all other things being left as before, and prepared for the comparison of the next day.

On the 18th of March, early in the morning, all being verified again and found in good state, the comparisons were repeated, with the results exhibited in the following table:—

Standards compared.	Micrometric readings subtractive from 78″,8.	Mean of the four results.	Correction of micrometer.	Corrected results to be subtracted from 78″,8.	Actual value of the distance.	Mean of the thermometers.
$\mathrm{M}^{c}+{}^{l}$	0″,044075					46°,6
$\mathrm{M}_{\text{ɔ}}+{}_{,}$	0″,043030					
Ends chang. to mid.		0″,043900	0″,0001756	0″,043724	78″,756276	
$\mathrm{M}^{\iota}+{}^{l}$	0″,043250					
$\mathrm{M}_{\text{ɔ}}+{}_{l}$	0″,043235					
$\mathrm{M}^{c}+{}^{y}$	0″,039175					
$\mathrm{M}_{\text{ɔ}}+{}_{\text{ʎ}}$	0″,039300					
Ends chang. to mid.		0″,039702	0″,0001588	0″,039643	78″,760357	
$\mathrm{M}^{c}+{}^{y}$	0″,040200					
$\mathrm{M}_{\text{ɔ}}+{}_{\text{ʎ}}$	0″,040135					48°,6
$\mathrm{M}^{l}+{}^{y}$	0″,041525					
$\mathrm{M}_{l}+{}_{\text{ʎ}}$	0″,040830					
Ends chang. to mid.		0″,041295	0″,0001651	0″,041130	78″,758870	
$\mathrm{M}^{\iota}+{}^{y}$	0″,041600					
$\mathrm{M}_{l}+{}_{\text{ʎ}}$	0″,041225					

The four double metre bars were now successively put under comparison, in their four possible positions, the inversion of the letters denoting the inversion of the bars:—

Standards compared.	Micrometric readings subtractive from 78″,8.	Mean of the four results.	Correction of micrometer.	Corrected results to be subtracted from 78″,8.	Actual value of the distance.	Mean of the thermometers.
Bar A	0″,044475					
∀	0″,044250					
Chang. end for end.		0″,0443690	0″,00017750	0″,0441915	78″,7558085	
A	0″,044325					
∀	0″,044425					
B	0″,043375					
ꓭ	0″,043750					
Chang. end for end.		0″,0433620	0″,00017340	0″,0431886	78″,7568114	
B	0″,043150					
ꓭ	0″,043175					
C	0″,043575					
Ɔ	0″,043775					
Chang. end for end.		0″,0437940	0″,00017520	0″,0436190	78″,7563810	
C	0″,043850					
Ɔ	0″,043975					49°,8
D	0″,043300					
ᗡ	0″,043100					
Chang. end for end.		0″,0433625	0″,00017345	0″,0431890	78″,7568110	
D	0″,043550					
ᗡ	0″,043500					50°,5

In the afternoon of the same day the comparisons of the metres were repeated, with the results presented in the following table :—

M^c+l	0″,045390					50°,3
$M_ↄ+ɩ$	0″,044625					
Ends chang. to mid.		0″,0448290	0″,00017930	0″,0446497	78″,7553503	
M^c+l	0″,044750					
$M_ↄ+ɩ$	0″,044550					
M^c+y	0″,040475					
$M_ↄ+ʎ$	0″,040525					
Ends chang. to mid.		0″,0408500	0″,00016340	0″,0406866	78″,7593134	
M^c+y	0″,040850					
$M_ↄ+ʎ$	0″,041550					
$M'+y$	0″,043175					
$M_,+ʎ$	0″,042450					
Ends chang. to mid.		0″,0426125	0″,00017040	0″,0424421	78″,7575579	
$M+y$	0″,042300					
$M_l+ʎ$	0″,042525					51°,8

To make these results comparable, it is necessary to reduce them all to one temperature, by the difference of expansion between iron and brass. I shall for this purpose make use of the results of my pyrometric experiments, made immediately after this comparison, and described in p. 224, Vol. I. N. S. of the Transactions of the American Philosophical Society, the mean results of which gave the expansion expressed in decimal parts of the whole length, for one degree of Fahrenheit's Scale, as follows:—

In iron,=0,000006963535
In brass,=0,000010509030
Difference,=0,000003545495

As all the details of the comparisons are here stated, it will be easy to apply any other expansion in the further calculation of the result, if desired.

The temperature having increased during the comparison with considerable regularity, and my work having been uninterrupted and uniform from the beginning of each series of comparisons to the end of it, the temperature corresponding to each of the results may be considered equal to the mean temperature between the two observed. The temperatures adopted in the table of results were therefore determined upon this principle.

I found it best to reduce all comparisons to the temperature of 32° Fahrenheit, or 0° Centesimal and Reaumur, for both the brass and iron, as we may easily obtain this temperature in nature, and it can therefore be presented by experiment; which would not be possible, if the value of the French measures at 32° were given in a length of the English brass scale at 62°, since this would always introduce a result of mere calculation. I shall reduce from iron to brass: so that the length of the metres will be given in English inches in brass, at the temperature of 32° Fahrenheit. The brass metre is therefore in this case considered as needing no reduction.

In the final reduction of the values obtained, I shall add, as a constant quantity, 0″,000172 to each result; this having been shown above, to be the surplus length of the individual division used over the mean length of the scale for 78″,8..

The following table will present the results of all the foregoing comparisons for the temperature of 32°, with all the necessary reductions:—

Dates of the comparisons.	Standards compared	Temp. at the comparison.	Immediate result of the comparison.	Fahrenheit, 32°.	Reduction for temperature.	Value at 32° Fahrenheit.
Mar.15 AM.	M^c+b	31°,4	78″,7607180	—0°,6	—0″,0000837730	78″,760806229
	M^l+b	32°,5	78″,7595370	+0°,5	+0″,0000698108	78″,759778811
	M^c+l	33°,7	78″,7602300	+1°,7	+0″,0004747134	78″,760876713
				+	+	
Mar.18 AM.	M^c+l	47°,1	78″,7562760	15°,1	0″,0042165000	78″,760664500
	M^c+y	48°,1	78″,7603570	16°,1	0″,0044957000	78″,765024700
	M^l+y	48°,9	78″,7588700	16 ,9	0″,0047191000	78″,763761100
	Bar A	49°,2	78″,7558085	17°,2	0″,0048028600	78″,760783360
	B	49°,5	78″,7568114	17°,5	0″,0048816200	78″,761865020
	C	49°,8	78″,7563810	17°,8	0″,0049704000	78″,761523400
	D	50°,2	78″,7568110	18°,2	0″,0050820400	78″,762065090
	A+B+C+D					315″,046236870
Mar.18 PM.	M^c+l	50°,5	78″,7553503	18°,5	0″,0051656700	78″,760687970
	M^c+y	51°,0	78″,7593134	19°,0	0″,0053055500	78″,764790950
	M^l+y	51°,5	78″,7575579	19°,5	0″,0054451000	78″,763175000

The principles of the arrangement of this comparison show that the result for each individual metre will be obtained by a simple equation of the following form, viz.:

$$c=\frac{(c+b)+(c+l)-(l+b)}{2}$$

and in like manner for all the others, by a proper mutation of letters.

The following table will present these results:—

Dates of comp.	M^c	M^l	M^b	M^y
Mar. 15, AM.	39″,380952064	39″,37992415	39″,379854162	
Mar. 18, AM.	39″,380964100	39″,37970040		39″,3840606
Mar. 18, PM.	39″,381151960	39″,37953601		39″,3836290
Means	39″,381022708	39″,37972015	39″,379854162	39″,3838448
Correction of Brass Metre, as per Certificate			+0″,000393810	
Brass Metre corrected according to Certificate			39″,380247972	

These results might now be compared with others: viz. with those obtained by M. Pictet of Geneva, in 1802, and those by Captain Kater, since mine were made; but as I have not the details of their operations and the expansion they used, on which it is evident that much depends, I shall omit such comparison here.

I shall confine myself to inserting the final results found by Mr. Troughton and myself, in London, in 1813, from a comparison of the two metres of Lenoir, in iron and brass, with Mr. Troughton's own scale, each metre being compared singly by the help of the butting pieces, as above described. They are:—

	Temp. of Fahrenheit.	Correction	Value at 32°.
M^l=39″,3783658	45°,5	(for temperature.) +0″,0018848	39″,3802506
M^b=39″,3799395	46°,0	(for certificate.) +0″,0003938	39″,3803333

the brass metre requiring no reduction for temperature.

The mean of these two metres in this comparison may be considered as identical with the mean of the three in the comparison detailed above; and its difference from the mean obtained above for the same metres is equal to 0,00030789.

The consideration of all these results proves that all copies of metres tend to be shorter than the original from

which they are taken, from the circumstance that whenever they are worked, either by filing or rubbing, to bring them to the proper length, they acquire unavoidably a certain degree of heat occasioning an expansion which does not subside fully, before the comparisons which direct the standarding are finished. The metre being therefore rendered equal to the original under these circumstances, will be found too short, when it is completely cooled down. Thus the metres made by Lenoir are both shorter than the original metre of the Committee of Weights and Measures. It is from this consideration that I did not bring the bar fully to the measure, but it still remained considerably above the proper length. Being however engaged in the comparison, I disliked changing it, and thereby overthrew a part of my work, wishing to delay it for a future time.

On the 21st of March, I took the different standards of the toise under comparison.

The toise of Canivet being half an inch French in thickness, and the English brass scale half an inch English measure, the microscopes were adjusted to fit this toise without parallax, and then the difference was compensated by laying four thicknesses of white paper strips under the whole length of the scale. The other toises had strips of proper thicknesses laid under them to bring them to the same focus.

The distance of 76″,8, which is nearest to the length of the toise, was taken between the microscopes, from +2″ to 78″,8 on the scale, placing them nearly at equal distances from both ends.

The value of the micrometer was determined by repeated measurements of the decimal on the scale between 78″,7 and 78″,8, which decimal was found to measure 0″,10053 by the micrometer.

I intended, as before, to determine their value by other intervals also; but this being deferred until the end of the operation, as well as the determination of the value of the distance used in mean distance of the scale, neither of

these measurements has yet been made, on account of the interruption necessary in order to make the pyrometric experiments before the breaking up of the winter. The micrometer values indicated in the results are however corrected for the above value, and represent therefore actual decimals of the individual subdivision mentioned. From this circumstance, the comparison remains confined to the distance used on the scale; but it may easily be extended, by measuring this distance, as indicated, on as many other parts of the scale as admissible; and the difference will probably not be much.

When the microscopes were screwed fast in their places, the 0° point of the micrometer did not exactly agree with the division of the scale from which it was intended to read. Instead of adjusting it by the screw which guides the slider of the micrometer and the divided head of the screw, I preferred ascertaining carefully the point of coincidence on the division and on the micrometer, and to adopt this last as the 0° point of the micrometer, from which the divisions were to be subtracted, since the micrometer was read from 78″,8 backwards, or by subtraction. The point so determined was 78″,8001375; or the actual distance from which the readings were subtracted was 76″,8001375.

The repetition of the comparisons with the microscopic readings direct, which I had also the intention of making, was prevented by the circumstances stated above; and I never afterwards could bestow any time upon this subject, before the collection left my hands.

The abridged notations for the registering of the comparisons are as follows:—

C	denotes the toise of Canivet.
L	Lenoir.
l^A	the copy of the toise of Lalande marked A.
l^B	the same marked B.

the inversion of the letters denoting that the marks on the

toises are downwards, the erect positions that they are upwards.

The length of the contact in the toise of Canivet is about two-thirds of an inch. In this three points were observed, as marked Plate IX. fig. 8, between *mm*, in the middle; between *ii*, at about one-fourth of the contact with the matrix from the inner corner; and between *ee*, about 0″,05 from the end of the contact. The toise was of course kept with the matrix, as this formed a proper butting piece to observe by, though the line was not altogether as sharp as that with the butting pieces made for the other standards. The breadth of the matrix prevented me however from turning it end for end, as there was not room enough between the microscopes and their supports.

The following table will present these comparisons:—

Toises compared.	Micrometer readings subtractive from 76″,8001375	Mean of the readings.	Correction of micrometer.	Corrected readings.	Value of the scale or measure.	Temperature.
C^m	0″,058250					33°,4
C^i	0″,059500					
C^e	0″,056400					
Chan. end for end		0″,0576958	0″,0003058	0″,0573900	76″,7427475	
Ɔ^m	0″,057050					
Ɔ^i	0″,058675					
Ɔ^e	0″,056300					
L	0″,061530					35°,1
⅂	0″,060550					
Chan. end for end		0″,0606200	0″,0003213	0″,0592987	76″,7408389	
L	0″,060700					
⅂	0″,059700					36°,9
l^A	0″,061020	0″,0618350	0″,0003277	0″,0615073	76″,7386302	
ꞁ^A	0″,062650					
l^B	0″,053600	0″,0536750	0″,0002845	0″,0533905	76″,7467470	
ꞁ^B	0″,053750					
						39°,0

The results of this table are now to be reduced to the standard temperature of 32° Fahrenheit, as was done for the

metres; for which I shall again use the results obtained by me, and stated before :—

Toises compared.	Temperature.	Immediate result of the comparison.	Temp. —32°.	Reduction for temperature.	Value at 32°.
			+	+	
C	34°,25	76″,7427475	2°,2	0″,00059722	76″,74334472
L	36°,00	76″,7408389	4°,0	0″,00108820	76″,74192710
l^A	37°,40	76″,7386302	5°,4	0″,00146921	76″,74009941
l^B	38°,50	76″,7467470	6°,4	0″,00174145	76″,74848845
$\frac{l^A+l^B}{2}$					76″,74429393

At the time of comparison of the two toises of Lalande in 1765, when compared with Bird's scale, the mean of both was 76″,734 at the temperature of 62° Fahrenheit; and it was stated that it was 0″,024 longer than when determined by Mr. Graham, of which comparison I know no details. This comparison of 1765 reduced to 32°, by the results of my experiments on expansion, would give the mean of the two toises of M. Lalande, equal to 76″,742162. What expansion was used then, or whether any correction was applied for it, I do not know. I have no knowledge of other comparisons of the toise, except that which might be drawn from the determination of the distance over the British Channel, by both French and English measures, in the operations made by General Roy, and by Cassini de Thury, for the junction of the Observatories of Paris and Greenwich.

It is proper that I should observe here, that the toise of Canivet served to make the four toises for the base measuring apparatus, which was used in the measurement of the base line of about 42,000 feet on the Marsh of Morat in Switzerland, made by Mr. J. G. Tralles and myself, upon which the triangulation of Switzerland, begun by us, has been founded.

Though it is evident that the above comparisons of toises

give only individual results, yet it may be proper to mention, approximately, the ratio they give between the length of the toise and of the metre, omitting the toises of Lalande. The combinations which they give occasion to make, all give the metre, in parts of the toise, between 0″,513162 and 0″,513137. The Committee of Weights and Measures adopted, in the construction of the metres, the ratio, 0″51317. M. Delambre gives, in the *Base Metrique*, 0″,513111185 at $16\frac{1}{2}$° centigrade.

Description of the Apparatus for measuring Base Lines.

In all surveys of considerable extent, the exact determination of the line, which forms the base of the whole triangulation, is of the greatest importance.

This line forms the absolute unit on which all future units depend. It is expressed in terms of the unit of length employed in its admeasurement; and the extreme distances of the whole survey referred to it must correspond to the places which astronomical observations assign to them on the earth.

The measurement of a line may appear simple and easy in common life, where no minute degree of accuracy is required, and where commonly the line itself is of no considerable length.

In the application to large surveys this forms the most tedious part of the work; and presents, in its mechanical execution, difficulties, which have always called forth the inventive genius of the operators.

This is not the place to expect a history of the different means employed in determining this line, nor to comment on their comparative advantages or difficulties.

It may be easily conceived that the most minute care is required to determine the fundamental unit length of a bar or chain to be used in the measurement of a base, from the

standard unit of length measure, and that the standard unit employed in it must be well authenticated. The means which I used, and the authenticity of my standards, are detailed in another place, to which I must refer for information on this subject. I shall only observe that I had peculiarly authentic and well adapted means to obtain a multiple of the metre lately determined from the measurements of twelve degrees of the meridian in Europe, and to determine the length so formed in English measure. I was therefore lead to give this multiple the preference, and accordingly I formed bars of eight metres in length, which I considered as the longest that would be well manageable in the actual measurement of a base line.

Considering the principles on which the measurement of a base line must depend, it is evident that the problem requires:

1. To determine absolutely in space the extreme points of the unit employed in the measurement.

2. To make this line begin at any given point.

3. To give it a certain determined direction.

4. To ascertain its position with respect to the horizon.

To satisfy the first condition, the theory of mathematics applies most generally three rectangular ordinates, and it is easily conceived that in this case something similar must be mechanically executed by some means or other.

In all the methods hitherto used, the mechanical contact of the bars or chain with the point from which either a previous bar or a line perpendicular to the direction of the base is measured, has been aimed at, and as the moving of the bars in their perpendicular direction presents much difficulty, on account of their weight and friction, this has been obviated by small sliders measuring the intervals between the bars laid near each other in the direction, occasioning of course a vernier reading which required much care and attention to small quantities.

I considered an optical contact of the ends of the bar with the determined point preferable to any other, both for ac-

curacy and easy manipulation, and I obtained it in as perfect a manner as possible, by means of the following arrangement:—

This part of the apparatus is a microscopic arrangement, of which Plate III. fig. 1, presents a vertical section, of about the fourth part of their real size, showing all the screw motions in the direction of the three rectangular ordinates.

A compound microscope, *aa*, about seven inches long, is kept in a vertical position, by passing through two horizontal plates, *bb*, projecting from two columns, *ee*. It can be raised or lowered to bring it to the proper focal distance, and then held fast by the screws, *dd*, which press the spring of the circular part of the plates, *bb*, together.

The object glass of this microscope is formed of two halves of lenses of different foci. The one half will bring the image of a cobweb thread stretched over the end of the bar at *e*, about three inches from the lens, to the focus of the eye lenses: the other half lens will bring to the same focus the image of the rectangular crossing of two lines traced on a small plate of ivory, *h*, which is screwed to the middle of the thick brass plate, *ii*, at about six inches from the object lens, and adjusted in the collimation line of the microscope. The ends of the bar have, through the middle of their breadth, a semicircular opening, to admit the cobweb to be stretched across it, and to admit more light from the point *h*, to come to the microscope, as seen in its natural size in the horizontal section at *g*.

In using the apparatus, the images above mentioned are to be brought in contact as in a reflecting instrument, either by the screw of the microscope, or that of the bar, as the case may require. As the cobweb thread at the end of the bar is perpendicular to the direction of the base, it is best to place the rectangular crossing lines on the ivory plate, so as to make angles of 45° with the direction of the base. The contact will then be effected by making the image of the cobweb bisect the right angle thus formed. The microscopes themselves are to be placed so that the line dividing the two

half lenses may be in the direction of the base or bars, in order that the light from both objects may be as equal as possible, which would not always be the case in any other position. The microscope must of course be placed at the proper distance from the point *h*, so as to present a distinct image of this point.

It is evident, that by this arrangement the optical contact obtained is similar to that of the microscope reading on a circular instrument, and can be made with great ease and accuracy. The determination of the point of contact in the vertical direction is equally accurate; for the limit of only tolerable vision in the compound microscope, which for the cobweb has about three inches focal distance, is already very narrow, and within less than one-twentieth of an inch. This would hardly affect the level of the bars, and still less the difference between hypothenuse and base. But when the vision is carried to distinctness, it will be totally destroyed.

The two horizontal motions required to place the point *h*, and the microscope, are made, in the direction perpendicular to the bars by the screw, *kk*, revolving in the end pieces of the plate, *ii*, and working in the socket which projects above the middle of the lower plate, *jj*. In the direction of the bars, the motion is made by the screw, *ll*, which turns in the lower plate, *jj*, and works in the socket projecting from the circular piece, *mm*, below. The positions of these screws, when in actual use, are seen in Plate III. fig. 7 & 8.

The circular plate, *mm*, is encompassed by a ring, *nn*, which presses it down to the plate, *oo*, to which this ring is fastened, but in such a manner as to admit its entire revolution within them, by hard friction, as it is usually called. By the circular revolution of this plate, *mm*, the whole upper part of this apparatus can be placed in the position best adapted to receive the bars freely, as is represented in the figure.

The plate, *oo*, is about four inches and a half in diameter, and is fastened to the steel triangular bar, *pp*, which is about seven inches long, and which slides closely up and down in

the heavy brass truncated cone *qq* resting on three legs like *r*.

The steel triangle *pp* is moved vertically by the strong screw *s* of which the capstan head *t* is turned downwards, and rests against the smaller base of an inverted hollow cone *uu* screwed fast to the solid piece *q*. This screw *s* can be moved very gently, to bring the cobweb of the bar into the focus of the microscope, by a pin and handle fitted to the holes of the capstan head *t*.

The legs *rr*, which support this apparatus, are of wood, and a number of them of different lengths should be prepared to suit the inequalities of the ground within the limits of the motion of the triangular bar *pp*, by which the nearer adjustment to the focus is made. They screw in brass ferrules, which serve to connect them to the solid piece *qq*.

In the actual use of the apparatus, it is necessary to have at least three such microscopic arrangements, that while two of them are used before, the third may be left behind for reference in case of accident. This arrangement will be taken forward when the bar is laid off the second time.

The point *h*, so determined in space, becomes that from which, when the bar is moved forwards, the further measurement is to begin. By means of this apparatus, it remains steady in its place, and the bar, when laid down in the next position, is adjusted by making the cobweb at the other end coincide with the focus of the half lens corresponding to it, as at *g*; all motions are then made by the screw work on the bar apparatus, of which a description shall immediately be given.

The second and third requisites make it necessary that the bar which is to measure the distance should be adjustable in all directions. It will immediately be seen that the longitudinal motion is attended with the most friction, and must on that account be impeded as little as possible. This precaution however seems to have been overlooked in the

English base apparatus, where this motion was impeded by the weight of the whole box and its apparatus.

Plate IV. fig. 1 & 2, presents a horizontal and vertical section of the whole apparatus, placed as when in use.

The whole bar between the two foci of the microscopes consists of an assemblage of four iron bars each of two metres in length, and exactly of the same breadth and thickness as the metres constructed and standarded by the Committee of Weights and Measures in Paris in 1799. They are joined together end to end by means of two iron clamping pieces AA, a section of which, perpendicular to the bars, is seen, in one-fourth of its real size, in Plate I. fig. 2. Each of these pieces being clamped to its bar by the screw B, the two corresponding pieces of the adjoining bars are screwed, in order to make the contact of the bars, by the longitudinal screws CC, above and below the bars. The bars can be easily brought in contact, as any gap would be immediately observed; and there is no fear of compression, because the instant of contact is easily ascertained, and before any compression of the metal could take place, the friction of the screws B would give way, and restore equilibrium and contact.

This assemblage of bars stands edgeways upon rollers F of one-third of an inch in diameter, placed at short distances (so that each double metre bar may have four) in brass pieces DD, which bear also pillars of about one inch in length EE, rising on both sides of the bars and presenting a rounded surface to them like a section of a cylinder. This surface is near enough to the bars to prevent their vacillation, but not their motion. Different sides of them are seen at Plate III. fig. 2, 4, 5, and a plan of one of them is seen at fig. 3. In one of these pillars, which is directly above the screws for the motions of the bar, there is a clamping screw G, (Plate I. fig. 4) by which the longitudinal motion of the bars on these supporting pieces and rollers is arrested. From this point, therefore, the expansion of the bars is allowed to act with full freedom upon the rollers F.

The pieces DD, which are thus the immediate bearers of the bar, are fastened upon a wooden quadrangular bar H of two inches square and about twenty-six feet long, receding about seven inches from each end of the iron bar, Plate III. fig. 4, and Plate IV. To prevent, as much as possible, this wooden bar from warping in the air, it was formed of strips of wild cherry, glued together so as to break joints. To move this bar H in the direction of its length, and thereby also the iron bars, there is a brass frame K, Plate III. fig. 4 & 5, and Plate IV. with a screw arrangement adapted to one end of it, by three screws LL going through the wooden bar and the two brass plates which embrace it on both sides. Two strong perpendicular pieces MM, Plate III. fig. 4, of which one forms the butt end of the bar H, and the other is held parallel to it at the distance of eight inches, form the socket of the axis of the steel screw Q, which is about 0,6 inches in diameter, and which is hid in the brass framing K. It is turned by the milled head screw I, seen at the end of this frame, perpendicularly under the bar.

The piece P, which has the mother screw corresponding to Q, is fixed solid to the O, which lies flat in the bottom of the box to which it is fastened by four strong screws passing through the brass and the bottom board, and made fast by mother screws from the lower side of the board.

The piece P, having the mother screw corresponding to Q, has two friction rollers RR on its side, Plate III. fig. 5, which press against the upper plate N of the brass frame K, to prevent any rotatory vacillation by the friction of the screw.

By the screw Q, the measuring bars are evidently moved in the box in the direction of their length. This motion is fully eased by eleven rollers SS of about half an inch in diameter, passing under the whole breadth of the bar H. All lateral motion is prevented by steel springs T, pressing moderately against it from both sides, and which are fast to the uprights holding the rollers, so that the contact of the

cobweb on the bar with the image of the cross on the ivory, is made by it, when this bar is to be placed for going off again from the point determined by the position of the microscope.

The piece O, bearing above the mother screw corresponding to Q, has also a part X, going downwards through the bottom of the box, which forms the socket of a steel axis of two inches long and two-thirds of an inch mean diameter, ascending vertically from the brass mother piece Y, which runs upon the steel screw ZZ, by which the box containing all the apparatus above described is moved horizontally in a direction perpendicular to its length.

The screw ZZ is held by a strong brass frame which is fastened to the end of a board of an inch and a half in thickness, by screws exactly similar to those which fasten the piece O to the box. At the other extremity of the box, a strong circular socket is fastened by screws, receiving below an axis Y, exactly equal to that described before, and moveable in the same manner by another screw Z, equally fastened to the thick lower board Z′.

This lateral motion is again eased by twenty-four brass rollers *aa*, an inch in diameter and one inch and a quarter long, fastened below the bottom of the box, and so fixed that two are opposite to each other near the side of the box.

This motion being across the grain of the wood, there are screwed to the lower board Z′, thin crossing pieces *bb*, of very hard wood, and in the direction of the grain, upon which rollers move with great ease, and without making any impression.

The box of this apparatus is always carried upon the thick board Z′, and placed upon the tripods in a direction so nearly true, as to be within the limits of the screws ZZ; it is then placed by these screws accurately in the true direction, being guided by a telescopic arrangement at the top of the box, to be described immediately.

The strong board Z′, which supports the box with the bar apparatus, rests upon five tripods with elevating screws in

the centre, as seen in Plate IV. A number of these tripods, sufficient to support two lengths of bars, must be in readiness. They should have legs of different lengths, so that they may be raised or lowered, to suit the inequalities of the ground.

To place these tripods properly, so that the box may rest equally on them, it is necessary to have a large level, similar to those used by masons, and long enough to reach three tripods. It should have an alhidade hanging vertically by its own weight, with a horizontal spirit level, and an arc below consisting of as many degrees as the locality of the ground may require, as seen at Plate IV. fig. 3.

The box including the bars and the other apparatus described, of which XX is the bottom, is about nine inches in width and height at both ends and fifteen inches in the middle. It is strengthened at the upper part by seven crossing pieces *dd*, with notches holding the sides in their proper positions. There is no wooden cover to the box, as a piece of canvas is intended to be hung loosely over it, which prevents the inner part of the box from heating. At both ends there are projecting pieces, which widen so as to cover the microscope apparatus, and shut out the side light from the objects observed and the sun from the ends of the bar. They move on hinges, in order to turn them back on the sides of the box and to prevent them from injury. This arrangement is seen at Plate IV.

At the top of the side of the box, near the end where the screw motions are, a brass support *c* is adapted, having a telescope exactly equal to those on the ten inch sextants, and adjustable exactly in the same manner in its horizontal direction. It is of small magnifying power, so that a pin *f*, erected at the other extremity of the box, may be seen without parallax at the same time with a distant signal directing the measurement. It has a vertical wire in the focus to effect the adjustment of the box independent of the pin. It may not be amiss to place two such telescopic arrangements

on the box, one directed forwards in the manner described, the other backwards on the other side of the box. These will serve for the purpose of verification, and may be taken from the collection of instruments, of which all the parts are double.

It is evident that half the breadth of the box, or distance of the directing telescope from its middle, must be considered in viewing the signals used in the alignments of the base. This condition will be satisfied by making the breadth of the signals equal to that of the box, and by directing the telescope to the proper side of each signal in the fore and back observations.

In relation to the fourth requisite of the apparatus for measuring base lines, viz. the ascertaining of the position of each part towards the horizon, the simplest and easiest mode might seem to be to measure the line actually horizontal, and in case a difference of level should occur, in which it would be too inconvenient to follow the same level, to fall or rise to a different level by means of a plumb line. But this mode should not be adopted when great accuracy is required, as experience would soon prove to an attentive operator. The deviations from the level to be obtained will increase so as to be unsatisfactory, and the placing of the apparatus will be found too tedious, and at the same time liable to inaccuracy.

The measurements were generally taken as near as possible to the soil. This supposes of course that the lines measured in the intervals were all straight lines, which probably was not the case.

I considered that the shortest as well as most accurate mode of proceeding was to ascertain the true position of each bar when it was actually employed in the operation. Horizontal measurements, however, should be taken whenever the ground is favourable to them; and when this is not the case, the tripods should be fixed to the proper inclination by means of the level above mentioned.

The focal point of the cobweb on the bar being determined with great accuracy in respect to its elevation, (as is evident from the absence of parallax between the two objects,) we may measure from it in any inclination that occurs, without fear of error in the distance.

The following is the arrangement added to the bar apparatus to measure this inclination. It is seen in both figures of Plate IV. but more particularly in Plate III. fig. 4, 5, & 6.

Upon the strong brass frame K, forming the leading part of the wooden bar H, a sector of ten inches radius is screwed by its strong edge bar *mm*, (fig. 4) and presents itself vertically, its centre being at *h*, and the divided arc *g*, at the side of the head I of the screw Q. It contains an arc of upwards of thirty degrees. Upon the alhidade of this sector there is a spirit level of about seven inches long, adjustable to the 0° of the sector by the screw *i*, which makes it revolve about the point *k*. The alhidade being moved by the tangent screw racking in the circumference of the arc *g*, until the level be obtained with the alhidade corresponding to any inclination of the apparatus, the reading of the vernier on the arc will indicate the inclination of the apparatus or the bars to which the sector has been adjusted.

For the reduction of the inclined distances to the horizontals, it is evident that a table of differences between the hypotenuse and base of a right angled triangle can be constructed to any degree of accuracy desired, the quantities of which referring always to the same unit, viz. the length of one full system of bars, will be taken out without any calculation, and their sum can be subtracted from the sum total at once.

Respecting the thermometers, it will not be necessary to say any thing here, as it is easily conceived that they must all be read at each laying of a box.

I might now describe the manipulation of this apparatus in the actual measurement of a base line, but I consider the use of each part of it so obvious to a person sufficiently ac-

quainted with these subjects, as to render such description unnecessary. Plate IV. presents both a horizontal and vertical view of the whole apparatus, as when actually employed in the measurement.

The safe transportation of the boxes between their placing and removal, from under the microscopes, will require considerable care, and also an arrangement to prevent the box from being put out of shape, in carrying it upon uneven ground, and by which in an extreme case even the bars might lose their contact. It will therefore be proper to adjust these bars, in case of any suspicion of this kind.

There being two complete sets of instruments in the collection intended for the survey, and a case seldom occurring in which both sets shall be employed at the same time, it may be convenient to use more than one full set in an operation. For instance, take more than three microscope stands. For greater security, take the directing telescope of the set not in use to make the back verifications of the line, by placing it at the other side and end of the box. Take additional rollers, thermometers, changes of legs, tripods, &c. &c.

The manner in which the journal of the measurement of a base line should be kept requires minute care, on account of the great number of observations and remarks to be inserted. I would here give a sketch or extract of such a journal, had I completed the measurement of a line with this apparatus; but the survey of the coast was interrupted before this could be effected. I shall however insert a few remarks, which occurred to me in Switzerland, when measuring with Mr. Tralles, now Member of the Academy of Berlin, in 1791 and 1797, a base line of about 42000 feet in length, and upon which the triangulation was founded. This base was measured twice: first, with a chain similar to that made by Ramsden for the English survey,—and secondly, with an apparatus of four toise bars, somewhat similar to that above described.

I shall place these remarks under the following heads :—

1. It is necessary to mark in the preliminary measurement and the alignment of the base a number of points, at equal and moderate distances from each other, so that at least one of these points may be found in each day's work of the accurate measurement, for the purpose of showing whether the length of a bar had been omitted, or written twice.

2. The journal must have regular columns for the observations made at the laying off of each box, and a column should be left for incidental remarks, the first column showing the number of each bar from the beginning to the end.

3. The time at which the adjustment of each bar is effected by the microscopic apparatus should be noted to the nearest minute. This may be entered in the second column. It is evident that this will serve to check the registering of the bars, by showing whether any mistake had been made that was not accounted for in the remarks inserted in the left column.

4. The stand of the sector, indicating the position of the bar towards the horizon, together with the stands of the several thermometers, marked and placed after each other in the order in which they have been read, should occupy the third or next column.

5. The points of coincidence of each of the marks stated in Art. 1 with the bar or any fraction of it must be carefully marked in the next column. Likewise the passage of any ditch, fence, or other permanent object that may be of use in finding any particular point in the line after having passed it.

6. At every fifty or hundred bars, a mark should be left behind, so accurately determined, that, in case of accident, the measurement might be again made from it, without the necessity of returning to the beginning. These marks should be numbered, and the time of placing them should be written in the journal.

7. In the evening, or at any other time when the work is suspended, the place of the last microscope apparatus taken off should be marked and registered in the journal.

8. At such suspension, the last microscope stand and the bar last layed off with its microscope stands adjusted, must remain in their places till the work is resumed. The whole must be covered with a tent, and well secured.

(A tent made for this purpose, with others made for the microscope stands, was delivered with the apparatus.)

9. Notwithstanding all these precautions, it will be proper to keep a constant watch over the apparatus when left out, and even perhaps to make a fence round it, if it be in a place where cattle pasture.

10. In the morning, or whenever the work is resumed, every thing must be carefully verified and noticed in the journal.

11. It is of course understood that the dates before and after noon, the state of the weather, the temperature of the exterior air at stated intervals, and any circumstances that may increase or diminish the confidence in the work at any time, must be inserted in the journal, and that it should contain a detailed account of the manipulation adopted, the persons employed, &c.

12. If the base should not finish with a full length of bar, as is generally the case, the last point determined by the bars should be carefully marked on the ground, and the complementary distance measured by means of a beam compass, or by any other means that shall lead to satisfactory results.

13. The measurement of a base line should be continued with as few interruptions as possible. Considerable trouble will then be saved in respect to covering, fencing, &c. the apparatus, and all sudden and unequal changes of temperature in the bars will be completely guarded against. I would therefore advise the operator to finish each day's measurement without interruption, and when this cannot be done, to suspend the work till a more favourable opportunity presents itself.

Description of the Two-feet Theodolite.

Plate V. presents a general perspective view of the instrument; and Plate III. fig. 7 & 8, the details of the centre-work in a horizontal and vertical section.

The horizontal circle *aa* is of two feet diameter, divided on a silver arch to every five minutes. It is fastened on six conical hollow radii *bb*, proceeding from a strong hollow hexagonal centre piece *c* of six inches in diameter, to which they are screwed fast each by four strong screws passing from the inside of the piece *c* into the strong base of the cone. The diameter of the cones is three inches at the base, and an inch and a half at the outer circumference of the circle.

Of these six radii, three reach only to the outer circumference of the circle, and the three others, intermediate between these, project about two inches farther, to receive the spheric nobs *dd*, through which vertical double screws pass, which level and support the instrument upon the truncated cones *ee*. These elevate the instrument sufficiently above the stand, to admit the verification telescope under the centre of the instrument.

The construction of these double screws for the adjustment of the instrument in levelling is best seen in the section of the Repeating Theodolite, Plate IX. fig. 2; as this construction has been applied to all the larger instruments, in order to render their adjustment more exact. *c'* is the outer screw, which is of brass, going into the mother screw perpendicularly through the nob, and having its milled head *c'* below it. This screw being hollow receives the steel screw *a'* through its whole length: the milled head *d* has below it a segment of a sphere, left rough so as to impress itself into the lead which is in the top of the cone *e*. The screws being placed so as to give play to the screw *c'* both in the nob and inner screw *a'*, the motion of the screw *c'* serves to

raise or lower the arm or radius of the instrument which it directs; and the inner steel screw having smaller threads than the outer c', the effect of its motion is proportional only to the difference between the distances of the threads of the two screws, by which means a very delicate motion is obtained.

By the three cones *e*, *e*, *e*, the instrument is fixed upon a solid stand of pine wood, the circular top board of which is two inches thick. A hexagonal frame underneath joins this board to the three legs, and at the same time preserves the top from warping. Pine wood was preferred, because it warps the least; and though, strictly speaking, a triangular board would be sufficient, the circular one is much preferable, on account of the protection which it affords to the instrument against accidental touches in passing round it during the observation. The board is, for the same reason, three feet in diameter; and I even took the precaution of placing the cones *e* always above the legs of the stand, to give the instrument more firmness. In the centre of the board is a hole, so that the centre of the instrument may be centered to the station by a plumbline hung from a loop in the centre below the axis.

The hollow hexagonal centre piece *e* above mentioned receives through its middle the bell metal axis *f*, Plate V. fig. 2 & 3, eleven inches in length, two inches in diameter at the bottom of the inner hollow part of the piece *c*, and an inch and a half at the top, which shows above the drum in the perspective view of the instrument, Plate V. The bottom part of this axis has a shoulder *hh* by which it is fitted into the hexagonal centre piece, and below it the plate *gg* projects to the outer circumference of the same hexagon, which serves to fasten the axis to this piece, by means of six strong screws, seen in fig. 8. The circular hole in the bottom of the centre piece *c* is the centre upon which the circle was divided.

The brass socket of the axis, by which the whole upper part of the instrument revolves upon the above axis, reaches

through the drum, and is fastened to it by the three circular plates forming the top, the bottom, and the middle plate of the drum *i*, Plate V. fig. 3.

This drum is nine inches in diameter and five inches and a half in height. From the side of it project three horizontal arms *l*, *l*, *l*, at 120 degrees from each other, which are hollow truncated cones similar to the radii of the horizontal circle, and of the same diameter near the drum, but much more tapering. Each of them bears at the end a strong piece *qq*, with a circular vertical hole to receive the compound micrometer microscopes by which the divisions are read off.

These microscopes are six inches long, and with a magnifying power of about fourteen times. They are marked A, B, C, in the direction of the numbers of the gradation. The degrees are only read by the microscope marked A, and are there indicated by the light index *m*, which projects from below the arm of the microscope, and folds back upon it when not in use. When in use, it is made visible by the microscope, when laid out so as to point close to the division, without however touching the arch, in order not to scratch it. The field of the microscopes embraces about 4,5 minutes of the division, so that there is never any difficulty in reading the smaller parts. The thirty minute marks being extended entirely across, like those of degrees, and the degrees distinguished by a strong dot in the protracted part of the line, always one or the other appearing in the field. The micrometer heads *nn* read in the inverted direction, on account of the inversion of the image by the microscopes, so that while the degrees go from right to left, the reading in the microscopes presents itself directly, or from left to right.

These microscopes being well known by various descriptions, it would not be proper to enter here into further details respecting them. They can be adjusted to 120 degrees by a small horizontal motion, which they admit in the pieces *q*, directed and fastened by three screws on the side

of these pieces at about 120 degrees from each other. The vertical adjustment of the whole microscope to the proper focus is made by two milled rings embracing the microscope, one above, the other below, the piece *q*. The adjustment for the arrangement of the microscope, as it refers to the proper situation of the wires with respect to the focus of the object glass, is obtained by screwing the lower concealed part into or out of the upper cylindrical part. It is held in its proper place by a small ring *b'*. As it is well known that these two last mentioned motions must always be made together, and the clearness of vision, absence of parallax, and accurate measurement must be obtained by both at the same time by trial, it will be sufficient here merely to indicate the screw serving for it.

A small screw *pp*, at the end of the micrometer opposite the screw head moving the rake or indented plate of the same which indicates its 0° point, will make the final adjustment to the division point, or the distance between the microscopes desired.

After some experience, I have, however, found it best not to adjust the microscopes to 120° distance, as it appears to me that the influence of a little deviation in this respect may be wholly neglected in comparison with the advantages of having the microscopes fixed simply in the middle of their holding pieces *qq*, which makes them more firm, and places the 0° point of the micrometer in the middle of the field of vision. I used them therefore always in this position, in which they remained perfectly steady, and which gave besides a kind of moral advantage, from the circumstance, that as the readings became thus different in minutes and seconds for each microscope, the observer remains entirely unprejudiced as to what he should read at each microscope, and each reading becomes thereby equally independent and impartial.

Upon the drum *i* are two spirit levels, four inches long, at right angles to each other, to serve for the first approximate levelling of the instruments, which I found, under tolerably

favourable circumstances of temperature, always exceedingly correct, and rivalling the large upper level, when that nicety of adjustment was observed which their smaller scale naturally required.

The transit telescope, which forms the upper part of this instrument and by which the angles are observed, is supported by two columns fifteen inches high screwed upon the drum at right angles to the microscope A. In travelling, these columns are unscrewed at *oo*, to prevent the box in which they are carried from being top heavy, and more effectually to secure them from injury; though I had the box also fitted to receive them with the instrument in some cases, in order not to disturb the upper adjustments of the instrument.

At the lower part of the drum, in the direction of the two columns, towards the right from the microscope A, is the arm *k*, made broad, but thin, so as to have sufficient strength in the horizontal direction and yet very little friction on the limb. This has the clamping and tangent screws, and presents itself always conveniently to the hand, in all positions of the instrument towards the observer.

The tops of the two vertical columns bear two pieces *yy*, projecting outwards to admit the axis, twelve inches in length, of the transit telescope, which is supported between them in rectangular Y's as usual. In one of these pieces, at *r*, is a screw, with a capstan head, showing through a cut in the side, which bears by the head upwards against the piece *y*, and by the screw part below against the uppermost part of the column, forcing the piece *y* upwards by the mere spring of the metal, and, between this bearing point and the screw *s*, fastening this piece to the column.

The telescope is a complete and very excellent transit instrument, describing a whole vertical, the eye end of the telescope having room to pass between the two columns without touching the top of the axis *ff*. It has thirty inches focal length, two inches and a half aperture, and four magnifying powers, the largest of which is about seventy-seven

times, and one of the middle ones prismatic. There is a lengthening tube of about five inches in length to the object end, to keep off the side light and shelter the object glass. It balances at the same time the opposite end of the telescope. Then equilibrium is established in all positions of the telescope without clamping, which always more or less affects the accuracy of its position.

In the focus of the telescope there are three fixed vertical wires, and one horizontal one moveable by a micrometer arrangement similar to that of the reading microscopes, by which small differences of level can be measured, as a very fine large spirit level can be hung lengthways to the telescope by two adjustable steel pins, on the side of the tube not seen in the figure. The vertical wires are of course adjustable like those of any transit instrument, by two opposite screws on the sides, as *d'*.

The middle piece of the transit is a zone of a sphere of five inches in diameter, to which the two parts of the telescope are screwed in diametrically opposite directions, and at right angles to these the two truncated cones, forming the axis. Their base is a circle drawn on the cord of about 120° of the central sphere. It diminishes to three-fourths of an inch at the other end, to receive the bell metal axis piece of half an inch in diameter. This shape presents a great strength of support against the sinking of the telescope by its own weight, while the central sphere is much lighter than the square formerly used, without any loss of strength.

This axis is perforated on one side to admit the light of a lantern placed on a piece projecting from the top of the column. A plane white glass is placed at the end of the axis, and in the spheric centre piece a plate, at an angle of 45°, perforated for the passage of the rays to the telescope. It is covered with gold leaf left unpolished, to prevent the glare of the reflected light on the wires. It admits of a small adjustment by the fastening screw *t* in the middle of the central sphere.

The lantern bearer is very light, slides from outside on

the piece *y*, so as to embrace it by two small pieces, and is screwed on from below by a finger screw.

The other end of the axis bears outside of its support a circle of six inches in diameter, divided on silver. Upon this revolves an alhidade of three arms, the two horizontal arms *u*, *u* serving to read on both sides by verniërs which are attached to them and to hold the spirit level. The vertical arm *v*, which is formed of the same piece of metal as the vernier arms, clamp these and the level, by the finger screw. The level being adjusted by hand, when so clamped, the telescope will, in revolving, read vertical angles with sufficient approximation to serve for finding a star, or determining any other elevation, within a certain degree of accuracy.

The adjustment of the axis of the telescope and the final levelling of the instrument are effected by means of a large spirit level *w*, suspended by hooks from both ends of the axis, outside of the supports *y*, *y*. As the space immediately under the axis is not free, it hangs on each side close to the columns. It is purposely without adjusting screws, and is therefore brought to adjustment by the filing of its hooks; and as the level is ground to a regular curve inside, the nice adjustment is made by two small ivory scales sliding upon the level, by two sections of tube holding to it by their spring. This is the arrangement of all the larger levels of the instruments, excepting those of the repeating circles.

Below the horizontal circle is a verification telescope, suspended in hooks from two opposite conical radii *b*, *b*, exactly similar in size and construction to the upper telescope, but of course without a vertical circle.

The eye end has a micrometer arrangement similar to the upper telescope, with one fixed wire in the direction of the length of the micrometer and three wires perpendicular to it, moveable by the micrometer screw. The whole micrometer arrangement stands at an inclination of about 15° with the horizon, so as to increase the chances of intersection with any distinct object within the field of the telescope.

The object end has a lengthening tube giving to this part some preponderance, by which the eye end is pressed upwards against an arrangement of three small sliding tubes x, which reach downwards from the limb of the circle, and present the rounded end of the finger screw z' to the upper part of the telescope. By the sliding of these tubes, and the final adjustment by the screw z', and the micrometer arrangement, the accurate pointing upon an object for the sake of verification is obtained.

As it cannot be my object here to go into such details of description as must be considered generally known, the above is, I believe, sufficient to explain all the peculiarities of the instruments, and to detail their principles and use.

Methods of Observing with the Two-feet Theodolite.

The limits assigned to the present papers rendered it necessary, in the description of this instrument, to suppose that a general idea of it might be obtained from the figures there given. The same reason now compels me to consider the general principles and method of levelling it, together with the adjustment of its line of collimation and axis, as well known, and to confine myself to the explanation of its peculiar properties, and of some theoretical principles and practical advantages not hitherto treated of, at least to my knowledge.

An observer furnished with an instrument with which he has never observed should first ascertain its properties and defects from the mathematical principles on which it is constructed. This will be more indispensable, when the instrument has had to undergo transportation.

In this inquiry he will be much assisted,—if, besides his

general scientific knowledge, he is acquainted with the manner in which the instrument has been constructed, and the peculiar abilities of the artist who constructed it. Judging from these circumstances the possible and proportional accuracy of the execution of the instrument, he will be able to direct his inquiry sooner to a satisfactory result.

In an instrument which is as perfect as possible, the adjustments are of course only accurate within certain limits, and he has to guard against the errors which he may be liable to in consequence of them, as well as against those of the instrument itself.

It becomes therefore the duty of an accurate observer in no case to rely merely upon the accuracy of his instrument and his own skill, but to adopt such a method of observing as will counteract, as far as possible, the errors of the instrument and those to which he himself is liable in making his observations.

Without such a method, and a regular system in his observations, his mean results will be under the influence of hazard, and may even be rendered useless by adding an observation, which would repeat an error already included in another observation.

It is possible to correct angles measured by an incorrect or ill adjusted instrument, by mathematical formulæ, when the data for the reduction are exactly known; but such data are always difficult to ascertain with sufficient accuracy. The reductions require longer calculations than the observations themselves, or at least are more tedious than a repetition of the observations. In a work of great extent, these reductions occur so frequently, and the calculations of the observations are at the same time so numerous, as to render any method, in which it would be necessary to retain them, extremely laborious. On the other hand, the observations may always be repeated in a way in which these corrections will compensate each other.

As to the instrument intended for the survey, which is the

subject of the present papers, I had reason to entertain the highest expectations. It was executed under my own inspection by that distinguished artist Mr. Edward Troughton of London, agreeably to our united views, and with that interest for its success, which the great friendship with which he was pleased to favour me could alone inspire.

The actual operations made at a station of a survey on solid ground, in a proper place, with good signals, &c. are in every respect best adapted for the trial of the instruments, and for devising a proper method of observing with them.

From the remarks which will be found in their proper place, on the method of dividing used in England, it may be observed and has been observed already by Ramsden in describing his dividing engine, that the exact placing of the axis in the centre of the division is still effected by trials and indirect means, and that when obtained exact, it may even lose this position by transportation or accident. It will therefore be proper to inquire whether the instrument be well centred or not, and, at all events, to use the indiscriminate mean of the two or more equidistant readings, which are now made on every instrument, as one single reading would be affected by the whole error of the eccentricity.

The half sum of any two vertical arcs in a circle is equal to the arc at the centre. Therefore the indiscriminate mean of any even number of opposite readings on an instrument will be equal to the angle at the centre. Also the third of of three angles at the same point out of the centre of the circle is equal to the angle at the centre of the circle. And in general it will be seen, that the indiscriminate mean of any number of equidistant readings will be equal to the angle at the centre of the circle. This property is new as far as I know, and may be demonstrated as follows:

Plate V. fig. 1.—Let C be the centre of the division, C′ the centre of motion, d the point on the limb marking the reading of the alhidade; Cd=the radius of the division. Then C′CM is the line joining these two centres (protracted),

and dC′M=the angle of the first reading with the line joining the centres. In the triangle dCC′, let

dC′M=ϕ
Cd =R=Radius of the circle,
CC′ =e =Eccentricity of the instrument; also

let $2n+1$ denote any uneven number of equidistant readings, into which the circumference has been divided, (as for even numbers, the demonstration is evidently made by the correction of two opposite readings,) and put β=the constant angle between the readings: Then we have dCM—dC′M= C′dC, and sin. $d=\frac{e}{R}\sin.\phi$ for the first reading, or that nearest to the line C′CM.

The second reading will give,

$$\text{Sin. } d'=\frac{e}{R}\sin.(\phi+\beta).$$

The third,

$$\text{Sin. } d''=\frac{e}{R}\sin.(\phi+2\beta).$$

And the $2n^{th}$ or last reading will be,

$$\text{Sin.} d^{2n}=\frac{e}{R}\sin.(\phi+2n\beta).$$

The sum of all the corrections will therefore give the following series,

$$\text{Sin. } d+\sin.\ d'+\sin.\ d''+\ \ldots\ +\sin.\ d^{2n}=$$
$$\frac{e}{R}\Big[\sin.\phi+\sin.(\phi+\beta)+\sin.)\phi+2\beta)+\ \ldots\ +\sin.(\phi+2n\beta)\Big]$$

The sum of the series in the parentheses is equal to

$$\frac{\text{Cos.}(\phi-\frac{1}{2}\beta)-\cos.(\phi+\frac{4n+1}{2}\beta)}{2\sin.\frac{1}{2}\beta}$$

the numerator of which is 0, for $(2n+1)_{\beta}=2_{\pi}=$the circumference of the circle; and which shows that the indiscriminate mean point indicated by all the readings will give the true angle at the centre of the division between any given point and the line of centres.

For any other series of readings making with the line of centres an angle$=\phi'$, the series of corrections would be similar to the above:

$$\text{Sin.}\,\delta+\text{sin.}\,\delta'+\text{sin.}\,\delta''+\ \ldots\ +\text{sin.}\,\delta^{2n}=$$
$$\frac{e}{R}\Big[\text{sin.}\,\phi'+\text{sin.}(\phi'+\beta)+\text{sin.}(\phi'+2\beta)+\ \ldots\ +\text{sin.}(\phi'+2n\beta)\Big]$$

The correction of the angle measured by these two series of readings will be equal to the sum of the difference of the two corrections for each microscope. Or,

$$=(\text{sin.}\,d-\text{sin.}\,\delta)+(\text{sin.}\,d'-\text{sin.}\,\delta')+\ldots+(\text{sin.}\,d^{2n}-\text{sin.}\,\delta^{2n})$$
$$=\frac{e}{R}\Big[\text{sin.}\,\phi-\text{sin.}\,\phi'+\text{sin.}(\phi+\beta)-\text{sin.}(\phi'+\beta)+\text{sin.}(\phi+2\beta)-$$
$$\text{sin.}(\phi'+2\beta)+\ \ldots\ +\text{sin.}(\phi+2n\beta)-\text{sin.}(\phi'+2n\beta),\Big]$$

observing that $\text{sin.}\,\phi-\text{sin.}\,\phi'=2\text{sin.}\tfrac{1}{2}(\phi-\phi')\text{cos.}\tfrac{1}{2}(\phi+\phi)$, and so on for the other arcs, the second term, or the sum of the corrections will become,

$$S=\frac{2e}{R}\text{sin.}\tfrac{1}{2}(\phi'-\phi)\Big[\text{cos.}\,\frac{\phi'+\phi}{2}+\text{cos.}\Big(\frac{\phi'+\phi}{2}+\beta\Big)+\text{cos.}\Big(\frac{\phi'+\phi}{2}+2\beta\Big)+$$
$$\text{cos.}\Big(\frac{\phi'+\phi}{2}+3\beta\Big)+\ \ldots\ +\text{cos.}\Big(\frac{\phi'+\phi}{2}+2n\beta\Big)\Big]$$

The series in the parentheses being that of cosines of arcs in arithmetical progression, is

$$=\frac{\text{sin.}\Big(\frac{\phi+\phi'}{2}+\frac{4n+1}{2}\beta\Big)-\text{sin.}\Big(\frac{\phi+\phi'}{2}-\frac{\beta}{2}\Big)}{2\text{sin.}\tfrac{1}{2}\beta}$$

whence,

$$S=\frac{e.\sin.(\frac{\phi-\phi'}{2})}{R.\sin.\frac{1}{2}\beta}\left[\sin.(\frac{\phi+\phi'}{2}+\frac{4n+1}{2}\beta)-\sin.(\frac{\phi+\phi'}{2}-\frac{\beta}{2})\right]$$

and since by the supposition, $(2n+1)\beta=2\pi$, $(2n+\frac{1}{2})\beta=2\pi-\frac{1}{2}\beta$ $=-\frac{1}{2}\beta$, the two sines in the parentheses become identical, and consequently $S=0$.

It follows therefore, that whatever be the number of equidistant readings into which the circumference is divided, the indiscriminate mean of all the readings will give the true angle at the centre of the division. It is evident that for three microscopes, $n=1$, so that $(2n+1)\beta=360°=3\beta$.

The same circumstance which occasions the eccentricity of an instrument, may also cause the axis of motion not to be perpendicular to the divided plane of the circle. The axis being placed vertical, by the adjustment of the instrument, the plane of motion, thus horizontal, will not coincide with that of the divided circle upon which the readings are made, and will require a reduction to the imaginary horizontal plane, which will be exactly analogous to the reduction of the ecliptic to the equator, and may be determined by the formula given for that purpose.

It is evident that in changing the position of the instrument, so as to make the legs successively change their places, the plane of the circle will be placed in the same symmetrical positions with respect to any angle measured upon it, as was the case in the readings of the angle; and the angles will require successive reductions corresponding to the same number of symmetrical arcs.

The indiscriminate mean of these angles, observed in all these positions, will again be the true horizontal angle corrected for the want of perpendicularity of the axis upon the divided limb.

Plate VI. fig. 3.—Let *ad* be the inclined limb of the divided circle, *ac* the horizontal plane, *a* the point of intersec-

tion of the two planes, d being any point observed on the limb. Drawing the arc dc perpendicular to ac, the corresponding point in the horizon will be c, and ac will be the reduced arc. Calling the inclination of the planes $dac=\alpha$; the constant equal angles between the legs$=\beta$, (commonly three;) and the distance of the point d from the intersection of the two planes$=\phi$; the series for the reduction of the ecliptic to the equator will give the corrections for each successive position as follows:

For the first position,

$$ad-ac=\delta=\frac{tg^2\frac{1}{2}\alpha}{\sin.1''}\sin.2\phi-\frac{tg^4\frac{1}{2}\alpha}{\sin.2''}\sin.4\phi+\frac{tg^6\frac{1}{2}\alpha}{\sin.3''}\sin.6\phi,\ \&c.$$

For the second position,

$$ad'-ac'=\delta'=\frac{tg^2\frac{1}{2}\alpha}{\sin.1''}\sin.2(\phi+\beta)-\frac{tg^4\frac{1}{2}\alpha}{\sin.2''}\sin.4(\phi+\beta)+\frac{tg^6\frac{1}{2}\alpha}{\sin.3''}\sin6(\phi+\beta),\ \&c.$$

For the third position,

$$ad''-ac''=\delta''=\frac{tg^2\frac{1}{2}\alpha}{\sin.1''}\sin.2(\phi+2\beta)-\frac{tg^4\frac{1}{2}\alpha}{\sin.2''}\sin.4(\phi+2\beta),\ \&c.$$

and so on for any greater number of legs and positions of the instrument. The sum of any number of such corrections being taken to ascertain the total correction as heretofore, and ordered according to their common factors, the following expression will result:

$$\delta+\delta'+\delta''=\begin{cases} +\dfrac{tg^2\frac{1}{2}\alpha}{\sin.1''}\Big[\sin.2\phi+\sin.2(\phi+\beta)+\sin.2(\phi+2\beta)+,\ \&c.\Big] \\[2ex] -\dfrac{tg^4\frac{1}{2}\alpha}{\sin.2'}\Big[\sin.4\phi+\sin.4(\phi+\beta)+\sin.4(\phi+2\beta)+,\ \&c.\Big] \\[2ex] +\dfrac{tg^6\frac{1}{2}\alpha}{\sin.3'}\Big[\sin.6\phi+\sin.6(\phi+\beta)+\sin.6(\phi+2\beta)+,\ \&c.\Big] \end{cases}$$

and so in case of more legs.

It is evident that the series in this sum are similar to that before considered, being the sums of sines of arcs in arithmetical progression, limited by the sum of the β's being equal to the circumference of the circle, which makes their sum $=0$, and proves the indiscriminate mean of the angles observed in the symmetric positions of the instrument to be the accurate horizontal angle.

In an eccentric instrument, it is of course impossible to make the microscopes measure exactly in all parts of the division, but the above shows that if they are adjusted in any one position, their measure will be corrected by the changes of position of the instrument, without having recourse to any other means.

Errors may also arise from a want of horizontality in the axis of the instrument. It is proper therefore to adapt the method of observing so as to correct these errors. But such errors are easily corrected in this instrument, by observing with the telescope in two positions diametrically opposite to each other.

In Plate VI. fig. 2, let *ab* be the horizontal line in which the axis should be, and *tp* the section of the true vertical plane which the telescope should describe. Instead of this let the axis be inclined in one position of the instrument, so that the telescope moves round the line $a'b'$, and describes a circle making with the vertical an angle $tct',=aca'=bcb'$. All the results of observations on objects taken in this plane will require a reduction corresponding to this angle. Turning the telescope so as to revolve through a semicircumference horizontally and vertically, and observing the same objects again without any change of the adjustments of the transit, the axis will come in the direction $a''b''$, and the plane of revolution of the telescope will make with the vertical the angle $t''ct=t'ct$; but on the side exactly opposite. All results of observations will require exactly the same correction as before in respect to quantity, but they will be negative in respect to the former, and the indiscriminate mean of the two will be

as before the true angle between the verticals of the observed objects.

This operation will besides bring the horizontal angle exactly to the points of the circle diametrically opposite to the former, and will again act as a correction in the same sense as the two mentioned before.

An error in the line of collimation will of course combine with that of the verticality of the circle described by the telescope, and be corrected partially by the double operation; but this adjustment is easily verified in this instrument.

An irregularity in the axes of motion of the instrument would of course have an influence on the observations; but in the horizontal angles, it is evident that this influence would be destroyed by the exactly inverted positions of the instrument in which the observations are made. This error therefore falls in with all the others, which appear of course always combined, and are finally compensated by a certain determined number of observations systematically arranged.

The only cause of error still remaining is the accidental error of any particular division, which might have been used in the series of angles. This chance can occur only by some particular accident in the work, as the dividing engine of Mr. Troughton is so regular, and his attention and care so great, that the error of the division may be supposed a minimum.

The displacement of my microscopes from their exact distance of 120° was too small to produce any influence on the accuracy of the compensations.

Upon the principles here demonstrated I grounded the following method of observing all horizontal angles with the two-feet theodolite.

1. Having carefully adjusted the instrument in all respects, the telescope is placed in such a position as to bring its eye end perpendicularly over the microscope A. In this position, which I call *direct*, I observe all the objects between which I intend to determine the angles at the time.

2. Then I turn the telescope round vertically, so as to

bring the object end of it perpendicularly over the microscope A, which position I call *reversed*, and observe the same objects which I had observed before; without any alteration in the adjustments of the instrument, not even its general levelling, if there has been no accidental derangement, but in every case without any alteration whatever in the adjustments of the transit telescope.

3. Then the theodolite itself is turned round horizontally for one change of legs or about 120°. So that all angles will now be read by each microscope at 120° from the former situation. In this position the instrument is again carefully levelled and adjusted in all respects.

4. In this second position the two operations before described are repeated; that is the same objects are again observed in both the direct and the reversed position of the transit.

5. After this the theodolite is again moved horizontally for one change of legs in the same direction as before, so as to come into the third possible situation, and each microscope to read again on the limb at 120° from its former situation.

6. In this third position, the same objects are again observed, both in the direct and in the reversed position of the transit; after the instrument has been adjusted in all respects as in any one of the two former positions.

By this method each angle is observed six times in the systematic order required for the compensation of all errors arising from the causes heretofore treated, and with much less trouble than if an equal number of observations were made by the merely accidental positions of the instrument, and as many observations would most probably be taken at all events of such points as would be considered as requiring great accuracy. The final angles are thus determined by the influence of eighteen angles on parts of the division symmetrically situated.

Experience has completely sanctioned this method of ob-

serving, by an accuracy in the final results never obtained without it.

I must here observe, in relation to the actual application of this method of observing in my triangulation for the survey of the coast, that it will not be found to have been rigorously followed; because it was the result rather than the element of that part of the work which I could execute. The necessity of advancing in the work, at the same time that I was bringing my method of observing to perfection both by theoretical researches and by practice, caused me to make use of all the observations obtained for both purposes.

In the examples of the Day-Book and the Journal of Results inserted at the end of the paper will be seen some fully registered in proper order. These are taken from the work on the Boundary Line with Canada, as I had not the opportunity of referring to any of my journals from the survey, having delivered them to the War Department.

The observations of the azimuths of celestial bodies, particularly of the sun, are very accurate and easy with this instrument. They should unite in one final result a complete system of the above compensating method of observing, besides an equal number of observations made six hours before and after the transit of the heavenly body used. This combination is necessary in order to render the elements for the calculations of the azimuths compensating to each other, and the influence of their error the smallest possible, as well as to make the observations the most favourable and accurate.

A full result of azimuths must therefore consist of twelve observations, which is not more than the number which would of choice be given to this element of the triangulation. With respect to the instrument, it will be the mean of thirty-six angles symmetrically situated upon the circle; so that the accuracy thus obtained must prove very satisfactory. In case that this complete series of observations cannot be obtained on a station, the only correction which may be omitted is that of the change of the theodolite upon its legs. All

the others are completely indispensable for obtaining a satisfactory result

In observing the celestial body, its transit is observed on all the three vertical wires of the telescope; and when the sun is observed, which is the most advantageous of all for azimuth determinations, the contacts of both limbs are taken. By this mode of observing, which is very easy, and even very pleasant, with this instrument, the most essential element of the azimuths, the time, is observed six times (with the sun) for each observation, which is of course a great advantage as to accuracy. I should even have wished that the telescope had five vertical wires instead of three.

The following is the order which I followed in such an observation:—

Having carefully verified all the adjustments of the instrument, and the telescope being in the position which I have called direct, I observed first the terrestrial object with which the azimuth was to be taken, choosing for it the signal which by its illumination at the time appeared the most distinct, and in case of equality in this respect, that nearest to the sun, and read off the three microscopes. Then I turned the telescope horizontally, so as to receive the transit of both limbs of the sun at all the three vertical wires, and having clamped the telescope in this position, I observed these transits, the time of each being carefully observed by a chronometer or clock to seconds and decimals, and written in the day-book by the secretary. After this I read the three microscopes on the circle.

Then I placed the telescope immediately in the reversed position, and observed the transit of the sun again as before, and after it the same terrestrial object again.

By this method the two azimuths are observed the nearest possible to each other, and the terrestrial objects observed, correspond to each position of the transit.

If the circumstances allow one more azimuth to be taken, without however admitting the change of the instrument upon its legs, and an assistant be at hand to determine the

time by the chronometer or clock, without taking the observer away from the azimuth, then the above second observation of the terrestrial object in the reversed position of the transit can be followed immediately by one of the sun in the same position of the transit; and returning the telescope to the direct position, one can again be made in this position, and the terrestrial object observed again for verification's sake, the terrestrial observation in the reversed situation serving for both azimuths in that position. Thus four azimuths, each from six transits of the sun's limb at the vertical wires, can be observed in a very short space of time.

It is evident that these azimuth observations would, whenever found necessary, be very well suited for the reduction to the mean time, according to the method invented by Mr. Söldner.

It is proper to make the azimuths as independent of the rate of the timepiece as possible, and therefore to make observations of time as nearly as possible before and after those of the azimuths; and if several observers should be together, a proper combination, which would admit both observations to be made at the same time, would be very advantageous.

The calculation of the result can of course be varied; being made either for each limb's transit, or, as I did, for each transit of the centre; but it is not allowed to take direct and reversed observations together in the same calculation.

The form of such an observation, and the manner of registering the results, will be seen in the corresponding examples of the Day-Book and Journal of Results.

I will here describe another method of observing azimuths, which may be of use in circumstances which admit only a portable transit and the means of determining the time. I applied it in 1793 in Switzerland, and it may sometimes be preferable to a measurement on a less accurate instrument. I adjust the transit telescope exactly in the vertical of the object, before the time when the sun will pass this vertical, and observing the transit of both limbs on all the wires, the time of the transit of the centre is thus obtained; and it is

evident that the result of the calculation of the azimuth of the sun will give at the same time the azimuth of the object, the time being determined by proper means as near to this observation as possible. In this manner the azimuths of all objects in the vertical of which the sun passes in the day (on both sides of the zenith) may be determined, and the terrestrial angles between them be tolerably well ascertained.

By the same method also an astronomical circle well adjusted in the vertical may serve for the determination of azimuths; and when it is required to lay off certain directions on the earth, signals may be placed purposely to observe azimuths upon them by this method; and if the sun should not at the time pass such a vertical, a star properly situated should be chosen for the purpose.

It is proper in this place to introduce some practical remarks relative to the illumination of the division, which has a considerable influence on the accuracy and facility of the reading. The light upon the divisions must be reflected from a white unpolished plane; it must fall upon the divisions in the direction of their length, and not from the side; and if the reflection from the limb enter the microscope, the greatest light will be obtained. All glaring light will be improper. I found white paper the most proper surface; and for this purpose I folded a quarto sheet into an octavo form, and to give it more solidity folded rims to the open sides; then giving to this again a fold in the middle, so as to make the two parts stand at right angles with each other, in the middle of one half I cut a circular hole exactly fitting the microscope tube below its holder, and adapted to it by its close fitting. The screw going over the whole length of the tube, it kept its position, and the other half hung down to within a short distance of the limb of the circle outside; the reflecting surface being thus a tangent to it, and nearly perpendicular to the limb. When the observer stands in the direction of the radius of the microscope, the light comes as from the centre of the instrument, reflected in the same

direction, and presents the divisions without any false shade, and very distinct. In any other position of the light or of the reflection, the strokes, which always present cavities, though they appear filled, will be viewed on the side, as one side of this cavity will always be in the light and the other in the shade; and the influence of this upon the accuracy of the reading is much greater than might be imagined, exceeding the limits within which it is possible to read with these microscopes.

For this same reason, night observations have not the same degree of accuracy on the horizontal limb of a theodolite as those made during the day; because in this case it is impossible to make the light fall in the proper direction, as no light can be placed in the centre, and outside, in the direction of the radius, it would occupy the place belonging to the observer. Night azimuths lose much on that account, and seldom give the satisfaction expected.

On the Signals and the System of Wires in the Telescope.

An object closely connected with the accuracy of the observation of terrestrial angles, is the choice of proper and distinct signals, and the adaptation of the system of wires to them.

In the first place, I must observe that objects seen from a great distance are visible rather in proportion to their difference in light and colour from the surrounding objects or the back ground on which they are projected, than in proportion to their size, which actually contributes very little towards the effecting of the vision, and is always detrimental to its distinctness. A small object seen by the shaded side, if projected upon a clear sky, will be visible at a great distance, and will be much more distinct, if it reflect the rays of the

sun to the observer. These remarks must certainly have been often made; and yet I have not seen that advantage has ever been taken of them for the purpose here in view.

A staff is always a bad signal, as it will always be seen differently according to the state of the illumination; and if it is furnished with a flag for the purpose of discovering and discerning it from other similar objects, this will easily mislead the observer as to its actual position, and certainly make it appear to stand out of the perpendicular, if at any considerable distance. Truncated pyramids are inconveniently large, and require peculiar reductions according to the side of them which is observable, and which may even change in the course of the short time of observation, by the change of the illumination.

For the vertical angles the staff cannot serve at all. The point at which it is fastened into the earth can never be ascertained with certainty, as it may be hidden by uneven ground before, or the ground from behind upon which it is projected may be mistaken for it. Truncated pyramids may be seen of different heights in different states of the atmosphere.

A signal showing itself detached from the ground on which it stands, will also be distinguished far better than a much larger one connected with the ground.

All these remarks I might support with daily experience, of which it will suffice to mention, that in a warm summer day, the gilt ball of a steeple may be seen at a great distance, when the steeple itself is only supposed, and not actually distinguished.

Making in 1798 a triangulation in Switzerland with a repeating circle with two telescopes, where the angles are measured in the plane of the objects, and the determination of the elevation of the triangle points being an object of interest, I was desirous of a distinct signal which should be seen equally in all directions: this lead me to the idea of forming spheres elevated on poles. They were formed of barrel

hoops, making the ribs of the sphere, and covered with white linen. Their diameters were from sixteen to twenty inches. They were very distinctly visible with the telescope on my instrument, though only thirteen inches in length, at a distance of fifty miles, and as far as ten miles with the naked eye; but they did not answer equally well in the lower atmosphere of this country near the sea shore, as was to be expected. I was therefore induced to use a kind of signals presenting a luminous point by the reflection of the sun, and adapted to the situation of that body at such times of the day as from the general state of illumination appeared to be most favourable to observation. In the middle of the day, the illumination will not serve at all for distinct vision, and even the largest objects become indistinct, on account of the vapour, (as this is commonly called); or rather because the reflection of the light from all objects goes upwards, and does not meet the eye of the observer on the surface of the earth.

As the cheapest reflecting surface which I could choose was sheet tin, and the construction of spheres became more difficult and expensive; and the spheres themselves always presented a small point, I chose the form of a truncated cone, under such an angle as would be the most favourable for the morning and evening illumination.

The next point which appeared desirable with respect to the signals was to find their places in case they should be removed. The means which I considered as best adapted for the purpose were the following:—

Plate VI. fig. 4.—*aa,bb* is a truncated cone of tin, the height *ab* equal to nineteen inches, the lower diameter *aa* equal to seventeen inches, the upper diameter *bb* equal to fourteen inches; the top *e* is a horizontal tin plate of three inches diameter, elevated five inches above the diameter *bb* which serves to nail the signal to the top of the pole *ef*, and from which to the diameter *bb* it forms a truncated cone of a greater vertical angle. The pole *ef*, upon which the signal is fastened, is about three or four inches in diameter, and of

such length as to bring the top *e* of the signal about eight or nine feet above the ground at *g*. The tin cone is held steady in its vertical position by two iron wires fastened at the lower rim *aa* of the cone, in diametrically opposite places, and wound round the pole, and making right angles with each other.

To place a signal, a hole was dug in the ground to the depth of about three or four feet, and of proportional width, and a permanent mark was then placed properly centred in the station. These marks consisted of truncated hollow cones of hard baked stoneware open at top and bottom, their height *ed* equal to sixteen inches, the inner diameter at the top *cc* equal to six inches, the lower diameter *dd* equal to twelve inches. They were at such a distance below the surface of the ground as to be perfectly secured from accidents arising from ploughing, &c.

The signals can be pulled out of these cones perpendicularly, and the holes filled with earth so as to leave no apparent mark; while at any future time the cones can be easily uncovered; and being emptied of earth, without being displaced, they will be prepared to receive other signals.

These signals answered in every respect perfectly well, and though constructed of apparently costlier materials than rough signals, the expense attending them, with the permanent mark in the ground, &c. amounted only to about three dollars and a half each,—a sum for which no pyramid, or any thing similar, could be constructed.

In favourable circumstances, these signals appeared like a strong luminous point, often requiring, when the signals were near, the use of a dark glass before the eye. Their form then became as distinctly visible as the limbs of a planet.

In distances of thirty to forty miles, they presented a distinct luminous point, when the sun was in such a situation as to reflect its rays directly to the observer, which time is of sufficient duration.

It is evident that the luminous point which was observed on the tin cone depended on the angle which the sun subtended with the line from the observer to the signal, and required of course a small reduction to the centre of the signal. To obtain this element of reduction easily, I observed always at intervals the sun to the nearest degree only, as no great accuracy is required, by placing the telescope of the instrument in the shade formed by itself, and reading the stand of the microscope A on the limb. Calculating the apparent angle subtended by the mean radius of the signal cone for each distance, I formed a small table, and placed it at the head of each station in the Journal of Results. The reduction was very easy, and was quickly made by a construction and a short multiplication of decimals, of which it is proper to give here the explanation, as well in principle as in practice.

In Plate VI. fig. 5, let *a* be the station point of the observer, *c* the centre of a signal observed from this station, *lbd* the mean circumference of the tin cone, and *as* the direction in which the sun is seen from the station, at the time of the observation.

For the purpose here intended, it is perfectly allowable to omit the correction of the azimuth of the sun, between the station point and that of the signal (which would be proportionate to the convergency of the meridians,) and also to suppose the lines drawn from the different parts of the signal to the observer as parallel, which would vary always less than the apparent radius of the signal.) This permits us to suppose, $das=cas=ccs'=fds''$.

By the principles of reflection, the point on the circumference of the cone which will be reflected to the point *a*, will lie at *d* the middle of the angle $s'ca$, supplement to the angle observed between the sun and the signal. The correction will therefore be proportional to *de* the sine of $acd=\frac{1}{2}.s'ca$, or to the cosine of the complement of it, that is to cosine $\frac{1}{2}cas$, or half the angle between the sun and the signal.

Expressing therefore the radius *cd* by the seconds and decimals which it subtends at the station *a*, the multiplication of this by the cosine of half the angle observed gave the appropriate correction or corr. $(cd)''\cos.\frac{1}{2}cas$.

To construct this correction with great ease, I divided a quadrant on pasteboard of one foot radius, numbered with the double angles as in a reflecting instrument, beginning to count as if from the point of the circle perpendicular to *ca*, which represents of course the position of the sun in the protraction of *ac* behind the signal. This radius was divided into ten parts, and lines drawn perpendicular to it, cutting the circumference in the corresponding points, indicating the angles to which they correspond. Upon a smaller piece, cut at right angles, one of these decimals was divided into ten parts again; this piece being slided along the line nearest to the angle observed between the sun and the signal, the subdivisions of it being perpendicular to the same, until these intersected the circumference at the actual observed angle, the tenths and hundredths of the radius corresponding to this angle, were indicated, these being multiplied in the seconds, tenths, and hundredths subtended by the radius of the signal, gave the correction corresponding to the observed angle.

This operation was of course of sufficient accuracy, and much shorter than the calculation either by natural cosines of the half angles or their logarithms.

Operating in the same manner for both signals, between which the angle is to be corrected, the total correction of the angle is obtained according to the following easy principles, which will be evident, without demonstration, from a mere inspection of the figure:

1. When the sun is seen between the two signals, the sum of the two corrections is added to the angle.

2. When the sun is behind the station *a* in the vertical angle of the signals, as in *hak*, the sum of the two corrections is to be subtracted from the angle.

3. In all other positions of the sun, with respect to the two signals, the difference of the two corrections must be subtracted from the angle.

The angle between the sun and the signal determining the angle at the centre of the signal between the station and the reflecting point, and being bisected, it is evident that the accuracy obtained by the method described is fully adequate.

When the sun does not shine, and the state of the atmosphere is such as to affect no reflecting point, which will happen in dull and cloudy weather, the whole signals will appear like a white surface and in full size; and accordingly if its centre be observed, no reduction will be requisite. The state in which the signals are seen is therefore one of the necessary remarks to be inserted in the journal.

The system of wires in the telescope is to be adapted to the form of the signals, in the same manner in which the wire arrangement in the microscope is adapted to the kind of division of the limb. In this instrument the division being by lines, the wire arrangement in the microscope is that of wires crossing each other under an angle of about thirty degrees, which in placing it by the micrometer upon the division, will present this angle bisected, and enable us to judge accurately of the coincidence.

With a similar view, I suppose, Mr. Ramsden applied this arrangement to the telescope of General Roy's theodolite in the English survey, where staffs were used as signals, while the division of the instrument being with points, the micrometer wires were simple perpendicular wires.

For my signals therefore, the perpendicular wires were best adapted; and as they were fine and exceedingly well defined cobwebs, they showed the light of the reflected point of the signal on both sides, by the irradiation, which of course afforded a very nice pointing, far preferable to the contact on the side of the wire, which has sometimes been substituted for the bisection by the middle.

I shall add one remark more:—

An attentive observer will find the object pointed at always disappearing when very near the wire, and as if it were broken off. In like manner, in pointing with the crossing wires upon a signal presenting a point, it will be impossible to place it actually in the vertex of the angle of intersection, and it will become visible only at a certain distance, standing free between the wires, without admitting actual contact with the wires themselves.

Additions made to the Repeating Circle with two Telescopes.

The general principles and construction of this instrument are well known from the descriptions given by French writers on the subject. The peculiar construction adopted by Mr. Troughton is described in the English Encyclopedias. I shall therefore suppose such construction known, and describe only the peculiarities of the two circles which Mr. Troughton made for me.

In the usual construction of this instrument, when an observation is to be renewed for the sake of repetition, the front telescope bearing the verniers is to be moved; no trace of the foregoing observations is left; their value in some measure is concealed by the position of the back telescope or level. In celestial observations clouds or intervening circumstances in general, which occur so frequently in observations, may at this moment render all previous attention and care useless; and the observer feels always somewhat anxious on that account.

It is however evident that the successive steps of the level or back telescope measure the angle in the same manner as those of the front telescope. Upon this consideration I founded a construction, by which the instrument gives two separate series of angles upon the same division, from the

same observations, by adding only one observation more at the end, and if accident should occasion the loss of one series, the other may be preserved.

Plate VII. fig. 1, is a general view of the instrument from behind, where the additions made to it are all visible. Fig. 2 represents a section of the limb and two readings, in the direction of a radius.

The limb of the circle consists of two circular rings fixed to each other, as seen in the second figure. A section of this limb or of the wings which form it resembles letter T. To the lower ring the radii *r* of the frame of the circles are fastened, the upper one being the divided limb itself, which is sufficiently elevated above the radii to give passage to the clamping piece D of the front telescope. The verniers of the front telescope, which are four as usual, reach to the division of the limb from the inside. To the back telescope and level, a frame, exactly similar to that of the front telescope, is adapted, with four verniers W, X, Y, R, which are fastened to the part of this frame extending beyond the circle by two pillars, bringing them round the limb outside, to reach to the division of the limb; so that there remains a sufficient space of the division free between two verniers to read them accurately, when two such verniers stand opposite each other. This space is about half the length of the strokes. The verniers then pass by each other freely, and are read upon the same division. The two magnifiers, which revolve upon the centre on arms, in the front of the circle, as seen in *b*, fig. 1, serve equally for both series of readings. As to the divisions, the strokes denoting degrees and half degrees are drawn out on both sides equally, so that they show equally for both the inner and the outer verniers. The degrees have points in the middle of the strokes, which will show when two verniers are opposite, and will serve to count them from the number seen on the left beyond the alhidade. Every ten degrees being engraved outside, and every five inside of the division, there is always a clear and equal reading for both positions of the verniers.

The verniers are all of double length, having on each side of the usual vernier one half length of vernier over, by which means two readings are obtained. A mean of these readings can be taken, in case of any difference.

The whole framing of the instruments is in general stronger in every respect than they were made before, and particular attention is paid to the stability of all the adjustments, as may be observed from a mere comparison of this figure with those in the Encyclopedia.

The breadth of the ring to which the radii of the instrument are fastened being about one inch, the distance at which the verniers W, X, &c. of the back alhidade must be supported by it would twist this alhidade by their weight, which would occasion them to read differently in different positions of the circle, as they would in all cases sink. This is avoided by adding on the side opposite to the vernier the nobs *a*, *a*, forming a counterpoise to the verniers, and effecting thereby their verticality in all positions.

To give more stability to the vertical or any inclined position of the circle, there are two semicircles *k*, *k* fastened to the horizontal axis *q* round which the circle is moved, close to the uprights supporting this axis at both ends, to which they are clamped by two screws *l*, *l*, instead of only one as in the former construction. There is also a small ball *s* upon the socket of the axis of the circle, between the counterpoise and the clamping arrangement *u* of the circle, adjustable by a sliding piece in the small upright *t*, which receives one of the axes of this level. The level swings on an axis, to serve in both opposite positions in which the circle may be placed by revolving upon the semicircles.

It appears to me, that in all instruments the alhidades should be clamped on a separate arm not bearing any reading, (when these are not upon a full circle,) because the clamp is very apt to affect the reading to which it is adapted. For this reason, the clamp and tangent screw of the back alhidade is put to the separate arm *n*, perpendicular to

the telescope and level, and the reading arms are all left to their natural spring. By this arrangement also, the assistant, who sets the level during the observation, acting in a more convenient position, is less liable to affect the position of the instrument by the weight of his hands; and there being milled heads at both ends of the tangent screw, as in all others of the same kind, he can act with great steadiness by applying both hands.

The good quality and power of the telescopes is a desirable requisite in the observations; for it will be found that a great magnifying power facilitates all the observations. Therefore, though the circles are eighteen inches, the telescopes are twenty-two inches, which the instrument bears very well; and I found that a power of about sixty-six times was the most advantageous for use. The object ends have light lengthening tubes of about three inches, adapted instead of the covers, and equilibrating the telescopes.

The front telescope has three horizontal and three vertical cobweb threads in the focus. The back telescope has only two crossing each other at right angles.

The four readings of the front telescope are marked in the order of the divisions by the letters D, E, F, G, which serve to register them properly in the journals of observations, in the same manner as those of the back telescope are represented by W, X, Y, Z.

As a very great convenience for night observations, Mr. Troughton usually adds to his circles a smaller divided circle, fixed to the part bearing the level, and to the telescope he adds an arm, reaching over the frame of the instrument to this circle. Sliding pieces are adapted to this circle, and being adjusted to the proper zenith distance of the star, on both sides of the zenith, will arrest the telescope in such a situation as to bring the star in the field of the telescope, by the horizontal revolution of the instrument. This arrangement underwent a slight modification, on account of the interruption which a long arm from the front telescope would have met with from the back alhidade.

An arm *f*, similar to that for the clamp, rises perpendicular to the level, from the centre piece of the back alhidade to the circumference. There it bends over to *d;* and has a circular ring fastened to it, going round the circumference and forming a complete semicircle *ddd*, which is again fastened near both ends to two knees *v*, extending from the level frame. This semicircle is divided upon the flat outer part, like the moveable quadrant of a globe. Upon this ring small pieces *e*, *e* slide by means of springs on their inner part, and present their projecting part to a small arm *g*, adapted to the front telescope, by which this is stopped upon the proper zenith distance to which the stops *e*, *e* have been placed. This piece *g* should be a very light piece of brass, made to spring or give way when it comes in contact with the stops ; so that it could not affect the position of the telescope in coming accidentally in contact.

The motion of the horizontal axis of the circle is stopped by the screw *u*, which presses to this axis an arrangement similar to the stop of a windmill; and the small motions are made by the screw at *m*, at the end of two arms, one of which is fast to this arrangement and the other to the centre piece of the horizontal axis *q*. To make this motion easy, the screw at *m* consists of two parts of unequal threads or paths, each going in the nut of its respective arm, and thereby causing the motion of the circle itself to arise only from the difference of the two screws. This motion is therefore as small as that arising from any other tangent screw on the instrument; and the use of the screws in the legs of the instrument can be fully dispensed with in this respect.

The horizontal circle of the instrument is fixed to the conical radii, which form at the same time the legs of it. The clamping and three readings A, B, C are adapted to the column forming the socket of the vertical axis of the instrument. A magnifier revolving round the lowermost part of the column serves equally for all three readings.

To stop the horizontal motion of the upper circle in the proper situation in respect to the azimuth, when stars are

observed at night, two small stops *n*, *n* are placed on the limb of the horizontal circle, and are fastened to it by a spring beneath it, and presenting their projecting parts on the limb to the sides of the alhidade A, in the two positions of the circle in which the star is met by a vertical plane passing through it.

Instead of the arrangement formerly used to produce a small vertical motion in the legs of the instrument, the screws are here again constructed on the same principles of two screws working in each other, exactly equal in all respects to those described in the two-feet theodolite.

On some Adjustments of the Repeating Circle.

It will not be expected that I should give here a full description of the adjustment of this instrument: it is too easy and too well known. But I have no where seen mentioned the most proper mode of placing the circle accurately in the plane of the vertical and of verifying the parallelism of the two motions of the circle and the telescope.

This consists in observing the pole star, (best in its greatest digression,) both directly and by reflection from a mercurial horizon. I do it in the following manner, whenever any more nicety is desired than can be expected from the mere placing of the two semicircles *kk* to the coincidence of certain strokes made upon them at *oo*, with the sides of the supports of the horizontal axis *q*.

Having carefully levelled the horizontal motion of the instrument by the large level on the circle, so that the verticality should take place by the above adjustment, the telescope is pointed to the pole star, and the horizontal motion clamped. Then reading the approximate altitude or zenith distance, the telescope is lowered so much below the horizon

as to receive its reflection from the artificial horizon, which is now placed in the situation indicated by the telescope, and sheltered from vacillation, if necessary, from the wind, by a glass cap.

If the motion of the telescope is exactly vertical, the reflected star in the mercury will coincide with the same vertical wire which was pointed upon the star viewed directly; if not, it must be corrected, half by moving the plane of the circle round upon the axis *q*, after unclamping the screws *l*, *l*, and half by the tangent screw on the horizontal circle.

If the circle is moved in the vertical, with the telescope clamped and every thing arranged as in the above observation, the verticality of its motion will be ascertained. If therefore there is any doubt respecting the parallelism of the circle and the telescope, it will be best to begin first by making the observation with the circle, the telescope being clamped, and when this is adjusted, to adjust the wires accordingly.

When these adjustments are made, and before any change in the level of the instrument takes place, the level *s* on the axis must be adjusted, and it will then serve to verify the verticality of the circle, as long as this circle is kept in its place. I therefore had the packing boxes so constructed, that the instrument might be removed without taking it apart, as I observed that the separate packing of the circle with the great counterpoise subjected the instrument to injury.

I think that some mechanical arrangement might be easily and advantageously adopted, for the purpose of giving to this adjustment a still greater degree of accuracy.

The illumination of the readings must be carefully attended to, as at night they are very difficult, and thereby become uncertain. I applied here also, with the best success, paper reflectors; folding a quarto sheet exactly as described for the two-feet theodolite; but instead of giving it a fold to bend it at right angles, I cut from about three-quarters of an inch behind the circular hole, which is here made so as to fit the tube of the magnifier, a slit to admit the arm of this magnifier, about two inches and a half long, and about

half an inch farther, another short slit, at right angles to the former. By these the paper was slided and held upon the arm of the magnifier, and screwed to it along with its tube. Holding a light on the opposite side of the circle properly, the light will be reflected very well on the divisions, and give a very good reading. During the day the free light will have the same effect.

It is useful to know exactly the angular distances of the wires in the telescope, and the values of the divisions of the level. The first are very easily determined by pointing upon a well defined object with the different wires and reading the verniers. The last are equally easy to determine in these instruments, having readings to the level motion, by placing the level on all divisions successively, and reading all four verniers. It is proper to repeat these observations when made, as the determination has regard to a very small quantity. Methods for this purpose will easily suggest themselves to a skilful observer, and a very good use may be made of the results, when accidents have disturbed the usual regularity of an observation. Still I do not approve of a method suggested sometimes, viz. reading the level, though not fully adjusted, and keeping account of its standing at each observation.

In one of these circles, the intervals of the wires were $8' 05'',3$ in the arc, and ten small divisions of the level sub- $27'',75$.

Methods of observing a Series of Vertical Angles with the Repeating Circle.

The instrument being well adjusted and levelled by means of the large level of the circle, I place the front telescope before the observation upon any convenient point of the cir-

cle, and read its four verniers D, E, F, G, taking a mean between the readings within and without their nominal, when any difference appears; or I read them in their accidental position, which may be that of the last preceding observation.

These readings are written in the third, fourth, fifth, and sixth columns of the Day-Book. In the second column the first letter of the series of readings is written, and the first column is left for the times.

In a night observation, the stops *e*, *e*, are placed to their proper zenith distance, allowing some free space for the quarter zenith distance of the star out of the meridian, and to avoid touching in pointing the telescope. The alhidade with the levels is moved so as to bring them near the projecting *g* of the front telescope, taking care to avoid actual contact. The circle is now turned so as to bring the level into an horizontal position.

By the horizontal revolution of the circle, the star will now appear in the field of the telescope, and when found, the horizontal stop *r*, fitting to the side on which the circle is, is placed in contact with the alhidade A.

Then the observer will make the accurate pointing upon the star or object, by the motion of the screw *m*, which guides the whole circle, while the assistant observer will adjust the level by its proper screw at the arm *h*. When both these are right together, the time is marked in seconds and decimals from a time piece by a second assistant, acting as a secretary. The time is written in the first column of the Day-Book before the readings of the front telescope, and forms the first time for the series of angles of the front telescope.

By the placing of the level, the verniers W, X, Y, Z come into their first position for the series of the level or back telescope. These four verniers are therefore now read off, and their readings written below the others in the same order, being marked in the second column by the letter W.

The circle being now brought on the other side of the column by a half revolution on the vertical axis, the observer

will move the front telescope near the other stop *e*, and make the second observation, pointing by the tangent screw of this telescope on the arm D, while the assistant will adjust the level, if it should be necessary, by the circle screw at *m*; though this adjustment will be very slight, if any, when the circle is well adjusted.

The time of the simultaneous coincidence of the pointing and adjustment of the levels is again noted by the secretary, and written in the first column before the readings W, &c. constituting the first time of the series of angles with the back alhidade.

Before turning the circle off, the observer will take care to place the other horizontal stop *n* to the contact with the alhidade A from this second position.

From this, the circle will be placed again in the first position, and the observations continued regularly and in the same order exactly to the last of the series, which must be like the first, an observation in which the level is placed by its own screw at *h*, so that the whole series consists of an odd number of observations.

The series being thus closed, all verniers of both sets are read off, those of the front telescope are written opposite to the time before the last, and those of the back alhidade to the last time, prefixing again in the second column the first letters of the set of readings.

All these will be observed in their regular order in the corresponding examples of the Day-Book.

By one observation more than is usual in the other circles, these give therefore two complete, equal, and (so far as refers to readings) independent series of observations. To that of the front telescope belong all the times, the last excepted, and to that of the back alhidade all the times except the first. They form a check upon each other against mistakes or errors, and may in some measure serve as a test of the proportional accuracy of different series of observations, besides that all results are evidently doubled.

The convenience obtained by the use of the screw *m*, for

the circle is such as to make the use of the screws at the legs for this purpose actually objectionable, as it brings the instrument out of its vertical and occasions always a tedious adjustment of the level; besides, that when a number of observations are to be made consecutively, it would be necessary to level the whole instrument again after every one, while otherwise the circle, once well adjusted, will remain so for as many observations as may be made in a whole night, if proper care has been taken as to the solidity of the stand, which, in the field, must always be placed on three plugs reaching deep into the ground.

It is evident, that the measurement of a series of angles in the plane of two objects may be conducted, in respect to the successive motions of the front and back telescope, exactly as has been described above, and the results taken in the same manner.

As two opposite readings correct the eccentricity, if any, it is evident that the indiscriminate mean of any two opposite readings should always be equal; but the different sinkings of the readings, and the different influence of the weight of the telescope and other moveable parts of the instrument, may introduce differences, as is well known and sufficiently discussed; therefore the indiscriminate mean of all four readings is also here to be preferred, and will ultimately be found to give a better result than a discrimination would give. The Day-Book examples will show, in their places, how I proceeded, in this respect, to scrutinise the results of my observations.

It is well known that this instrument is calculated to correct all its own errors by the effect of its repeating property and construction, particularly in the vertical angles. Still it is well known that (for instance in determinations of latitude) it is proper to take the indiscriminate mean of an equal number of results of observations from the north and the south side of the zenith.

For the same reason, if ever any doubt should exist as to the want of stability in the parts of the instrument, which

is very possible, the circle should be used in the two inverted positions which the semicircles admit.

Peculiar Method of Observing Time with the Repeating Circle.

In the observations for the determination of time, this element itself is the principal object of research, and may be considered as the most difficult to obtain accurate. The proper adjustment of the level in an observation of such a transitory nature, and during which the circle may move considerably in the vertical by pointing, requires great dexterity in the assistant; and since the level itself oscillates in passing to equilibrium, it is often very difficult to be sure of its position.

From one complete observation with the circle in its two positions and the indiscriminate mean of the four readings, all the main corrections of the observation are obtained. Succeeding observations serve only to augment the probability of accuracy, and to correct accidental errors of division, which, as already stated, may be considered a minimum in the instruments of Mr. Troughton.

A method satisfying the two first mentioned desiderata will therefore secure more accuracy in this kind of observation than the usual mode of repeating. My peculiar situation, with assistants entirely unacquainted with observations, joined to these considerations, led me to devise the following method of observing time, which I have ever since practised, and which Dr. Tiarks, the British astronomer for the boundary line at Canada, adopted also in our common works there.

The instrument being well levelled and the position of the front telescope read off as usual, the circle is placed so as

to receive the transit of the star, or both limbs of the sun, at all the horizontal wires. In this situation the level is adjusted with ease, sufficient time being given, by the placing of the circle; and the transit of the star, or both limbs of the sun, at each of the three wires is observed. This can be done with the greatest nicety, the instrument being at rest and all the observer's attention being directed to the time of contact which is rapid; the observer calling out *Null*, at each transit, the secretary being attentive to the chronometer or clock, can note the time with the greatest accuracy; and the transit of the sun's centre is determined by six observations.

The circle being now brought into its second position, by a semi-revolution on its vertical axis, the level will remain adjusted, if the instrument is well levelled. If it require any correction, this must be made by the circle screw *m*, as the position of the level upon the circle must be preserved.

The telescope is then unclamped at D, and again placed so as to receive the transits as before. These are observed and the time noted, as has been done in the first position.

This observation being made, the verniers of the front telescope are again read, and give the double zenith distance, or rather the sum of the two zenith distances at the times of the observed transits. The half of this sum is to be considered as corresponding to the mean time between the two transits.

Such an observation, when taken near the prime vertical, will not exceed the time allowed for taking an arithmetical mean, and will be the result of six or twelve observations of time.

If the transit of the sun is supposed to take too much time to observe both limbs on each side, the antecedent may be taken in the first position, and the consequent in the second. There being then but half the number of times obtained, the observation may be repeated after the reading, and a mean of two such observations taken, as in any other case, calculating each separate.

In all cases, the application of Mr. Söldner's method of reducing all observations to the mean time, by correcting the result for their respective distances from the same, applies here with great ease and accuracy, since for each transit the distances of the wires are equal on each side, as nearly as the distances of the wires are, and therefore the calculation of this correction may be made for half their number only. It will therefore always be found advantageous to apply this method in the calculation of the results.

This method of observing will be found very satisfactory in practice, in regard to accuracy and a saving of time, together with the facility of choosing it so as to come nearest the prime vertical.

This method will admit an observation of time to be taken among flying clouds, when the method by repetition would be inapplicable; and when no complete observation can be obtained, the observation of any pair of corresponding wires in both positions of the circle will at least give an approximate result, which will often be useful.

It would be very advantageous, in using this method, to have five horizontal wires in the telescope within a space near that occupied by the three, as the transits could easily be observed, and the gain for each wire would be double in the result. I have therefore sometimes applied them.

The registering of such an observation and the manner of taking the result will be found in their proper places in the Day-Book and the Journal of Results.

Description of the Repeating Theodolite of One Foot Diameter.

Besides the great theodolite, it was very desirable, as well for the intended survey of the coast as for other uses in the country, to have some instruments of the theodolite kind of

a smaller diameter, and yet capable of giving the same accuracy as the large instruments, though at the expense of more skill, labour, and time of the observer. It was also desirable that the same instrument should equally serve for vertical angles, in order to enable the observer to determine accurately latitudes, times, and the angles of elevation of the signals.

The multiplication of the terrestrial angles in the plane of the horizon was far preferable to that in the plane of the objects, on account of the great influence of refraction near the sea shore, particularly upon sandy beaches and islands, where it may be considered as varying constantly; and even a saving of time in the calculations was an object worth consideration.

It was necessary, on this account, that the instrument should be of the repeating kind, and a theodolite.

In planning an instrument to answer these views, the principles mentioned when treating of the two-feet theodolite and the repeating circle with two telescopes, lead me to unite the properties of both these instruments, omitting only the means of measuring angles in inclined planes.

In repeating instruments, the main points to ensure accuracy are,—the exact and steady levelling of the instrument, and the constant parallelism of the motions with respect to each other, in the course of the repeated measurement of an angle. These being secured, the plane of the divided circle itself, with its division, serves as a mere indicator of the operations, which has no influence until in the final reading of the stopping point, by the amount of the reduction of the distance of it from its intersection with the real horizon and by the accidental error of the division used, which have been shown to be the two smallest errors. The influence of eccentricity being corrected by the indiscriminate mean of the three readings, and the instrument admitting all the systematic combination of the series of angles which the two-feet theodolite admits for the single angles.

The same principles, as far as relates to the mode of mul-

tiplying and the motions of the axis, could evidently be executed in the vertical as well as in the horizontal circle. By making the latter revolve in the manner of a transit, not only all counterpoising weight might be avoided, (and therefore the weight of the instrument very much diminished,) but also its stability in the observation might be secured.

Upon these considerations I founded the construction of an instrument, of which I presented a plan in full size to Mr. Troughton, who, approving the principles, thought however, at first, that with eighteen inches diameter, as I wished it, it would present some difficulties, and therefore executed two of them of twelve inches in diameter, availing himself of the liberty left to him, as a skilful and experienced artist, to alter in various respects their external appearance.

Plate VIII. fig. 1 is a full perspective view of the instrument, and fig. 2 is a vertical section of the horizontal circle through the centre.

The centre piece *aaaa* of the stand part is two-thirds of a strong sphere, perforated to receive the axis of the horizontal circle. The three hollow conical arms forming the legs of the instrument are fastened to this piece by large strong screws, which are stopped below by the small screws *b*, *b*.

These arms terminate in spherical nobs which receive the vertical double screws *a′*, *c′*, in the same manner as in the two-feet theodolite and the repeating circle. They rest upon three truncated cones having lead in the top, and being sufficiently elevated to admit the verification telescope between the instrument and the stand.

The vertical axis *cc* of the instrument is fitted in the spheric centre piece by a collar, in the same manner as in the two-feet theodolite, and fastened by six screws from below. The lower part of this, represented by *ee*, is nearly two inches high, and forms the axis of the horizontal circle, which revolves upon it by means of the socket *dd*. The upper part, seven inches long, has its diameter diminished so as to leave a collar *ee* of about one-tenth of an inch to rest the upper part of the instrument upon. This socket is in the

middle between the two columns *g*, *g* which support the axis of the upper telescope and circle, and is connected with them by means of the plate *ll* of about half an inch thick, and the cross piece *f* at the upper end of it.

Upon the spheric centre piece *aa* is fixed a circular ring *hh*, having three radii in the direction of the three legs of the instrument, which bear at their ends the three verniers D, E, F, with a clamp and tangent screw at D. This holds the circle *dd* by its lower plane, which is also that of the radii of the circle.

The divided limb of the circle *ii* is elevated above the other plane, so as to leave both on the inside and outside a recess sufficient for the clamping parts of the inner and the outer verniers. The inner clamp and tangent screw at A clamping and leading the upper part of the instrument, has the three verniers A, B, C reaching upon the same division of the limb *ii*, and affording readings for both the forward and the backward motion of the telescope. These motions are required in measuring an angle by multiplication. For, alternating between the two clamps at A and at D, the circle will, in one motion, move with the upper part of the instrument, and in the other remain clamped to the stand part.

The reading glass is on a detached part, consisting of a piece *m* about an inch and a half long, two-thirds of an inch broad, and one-third of an inch thick, bearing at one end a small pillar, upon which the projecting arm revolves. This brings the magnifying glass, with its reflector over any vernier required. At the other end a solid nob forms, at the same time, a handle and counterpoise to the magnifier. The reflector is a circular plate of brass lined below with plaister of Paris.

The two columns *gg* rise from the strong plate *ll* on both sides of the centre, so that their bases touch the base of the central cone which forms the socket of the axis. They are about two inches and a half in diameter at the base, and fifteen inches high. Each carries upon its top a solid piece *yy*,

which projects a little more than an inch beyond the column, to bear the supports of the transit axis of the telescope.

The axis of the transit is nine inches long. Its two parts, as well as the two parts of the telescope itself, are screwed in a spheric centre piece of about two inches and a half in diameter, and are in all respects similar in construction to the telescope of the two-feet theodolite. The telescope itself is nineteen inches long and of two inches and a half aperture. It has a lengthening or rather sheltering tube before the object glass, and in the focus three vertical and three horizontal threads of cobweb. The eye glasses are exactly the same as those of the two-feet theodolite and repeating circles; so that they will serve for any of these instruments in case of loss. The largest magnifying power is about forty-five times.

On the side of the telescope tube opposite to the circle, there are two small pins or axes, which are adjustable, and, by receiving a level constructed for the purpose, make this telescope serve as a very fine levelling instrument.

Through one side of the axis the wires in the focus are illuminated by the lantern which is placed upon a light projecting piece opposite to the axis, and fastened to the piece *y* by a screw.

The other part of the axis of the telescope forms the axis of the vertical circle, which revolves upon it in a manner exactly similar to that of the horizontal circle upon its axis.

An alhidade, bearing two diametrically opposite verniers W, X, is fastened to the axis of the telescope by its middle circular part, and forms the outer reading upon the divisions, exactly as in the horizontal circle, and clamps in like manner to the outer part of the limb.

A triangular piece, of which one side is horizontal, bears the two diametrically opposite readings Y, Z, reaching upon the division from the inside, and clamping to the limb of the circle by means of the inner recess between its plane and the plane of the radii.

To the angle of this piece, which is turned downwards, is attached a piece *q*, which bears a steel pin fitting in a vertical slit in the bar of the triangle, which prevents all angular motion of this piece around the column.

In the middle, between the two verniers of the bar of the horizontal triangle, is the centre socket *p*, within which the axis of the telescope revolves. This socket, and that of the telescope, are held to the axis by the ring *u*, which is screwed to the shoulder of the bell metal part of the axis of the telescope forming the axis to these two motions.

The two magnifiers, which serve for all readings, revolve with their arms, round the socket of the triangle. They are fixed to a ring that turns round this socket, and which is held in its place by the projection of the same piece *u*.

In observing vertical angles, the circle is clamped alternately to the alhidade of the telescope or to the triangular piece, by the alternate use of the clamps at X or at Z, and the two series of motions give two separate series of angles, each with two diametrically opposite readings.

All the verniers of both circles are double in this instrument, as in the repeating circle, having one half vernier on each side.

The adjustment of the axis of the telescope is made by two strong screws under the pieces *y*, *y*, showing a capstan head at *r* in the uppermost plate of the column, and pressing these pieces upwards by their spring around the screws *s*, by which they are held fast to the columns.

A detached level is placed upon the ends of the axis, passing between the radii of the circle, for the final accurate levelling of the instrument. When the instrument is adjusted, this level is removed and placed upon an arm *t*, at the top of the column opposite the circle, in a position parallel to the same, and there adjusted by a screw, below one end of the arm, to serve as a constant test of the stability of the level of the instrument during the observation.

By bending the lower angular part of the triangle above

mentioned a little inwards, it may be disengaged from the pin in the piece *q*, which holds it in its position. Then the axis of the telescope can be lifted out of its supports, and the whole upper part, which serves to measure vertical angles, can be taken off, and placed in an inverted position for the verification of the line of collimation of the telescope, though it can not serve in this inverted position for the measurement of vertical angles.

The verification telescope below the instrument is exactly similar to the upper, and can, if desired, be used in its place. It hangs in hooks *x*, *x*, one of which hangs from one of the legs, and the other from an arm of the stand part of the instrument, purposely intended for it. It is pointed in the same manner as that of the two-feet theodolite, by an arrangement *w* of three sliding tubes, and a screw presenting its head to the upper part of the telescope tube at the eye end, which is pressed upwards to it by the overpoise of the object end.

To ease the first approximate levelling of the instrument, there are two small levels *k*, *k*, about two inches and a half long, and half an inch in diameter, placed at right angles to each other, at the side of the socket of the axis, between the two columns, on the side opposite to the vernier marked A, which in the figure show only a little between the axis and the columns.

The elevation of the upper telescope above the horizontal circle increases the facility of observing very high altitudes. The eye end passes through the nadir above the piece *f*, crossing the top of the vertical axis. The whole instrument is about thirty-two inches high, and the base of it through the truncated cones is a circle of about nineteen inches in diameter. It is therefore well proportioned for stability, particularly as the upper parts are not heavy.

In my original plan several of the arrangements were different. They were executed with great success in another instrument; and every artist or practical experienced observer will of course vary the disposition of many of the parts

according to his own convenience and experience, and also according to the particular skill or means of the artist who constructs the instrument. The high opinion which I had reason to entertain of so distinguished an artist as Mr. Troughton induced me to leave much to his judgment and ideas.

I had the horizontal circle constructed so as to have the axes of both motions. The centre part had cones both downwards and upwards. The axis downwards revolved in the centre of the stand part. The legs of this were inclined from the centre to the circumference where the perpendicular screws come and upon which the instrument stands. The other axis receives the upper part of the instrument by means of a socket similar to that in the other instrument, but much shorter.

These two axes were of bell metal, with steel rings at their inner and outer ends. They were differently proportioned to each other. The lower was about twice as long as the upper, and of a more acute conical shape, in order to give it a greater wedging power; which, with the greater superincumbent weight on it, when the circle is moved with the upper part, increased its friction. The upper axis was about two inches long; its lower diameter was about the same length, its upper less than one inch. The socket of the axis lay close to it, and moved with ease, as the weight of the upper part was light. Accordingly, in moving this part, the great weight of the horizontal circle, and its great friction prevented all dragging of it after this motion. This, in the instruments made by Mr. Troughton, and in which the horizontal circle is light, is prevented by completely detaching the circle from the upper part, when the clamp A is loose.

Mr. Troughton's objection to this shape of the axes was, that they could not be rubbed so well with emery in a kind of screwing motion which takes off all the rings of turning and renders them smooth. But as these rings always form themselves in the instrument by use, I should think that in

vertical axes there is no bad influence to be apprehended from them.

The vertical circle being supported in this kind of instruments between two columns, it is subject to less spring, and has much more stability than in the circle with two telescopes, where the double weight of the circle hangs upon a short axis, upon which equilibrium is maintained between the circle and its counterpoise. The verification of the verticality by the pole star can be made with the greatest nicety; and the large detached level itself can be adjusted upon it.

Method of Observing Horizontal Angles with the Repeating Theodolite.

The adjustments of this instrument are evidently the same as those of the two-feet theodolite, and grounded upon simple and well known principles, which are self evident from a view of the instrument, and need therefore not to be explained here.

The use of common theodolites with double axes for the repetition of angles is also so well known, that the mere description and view of the instrument would lead to the use of these double repeating theodolites, yet it may be proper to describe here the mode of taking a regular series, in order to render more intelligible the other pecularities which are to be mentioned as means leading to the greatest accuracy.

When the instrument is carefully levelled, the riding level is placed upon the arm *t*, parallel to the vertical circle, and there adjusted.

Then the vernier A being placed upon 0° or any other division, which may also be the last reading of a foregoing se-

ries, the stands of the verniers A, B, C are inserted in the Journal. The clamp D being loose, the telescope part, together with the circle, will be turned so as to point the telescope upon the object to the left of the observer, and the pointing made by the tangent screw at D. After which, the three verniers D, E, F are read off, and inserted in the Journal. It is best to write them consecutively in the six first columns of the journal, heading each with its proper letter; the superscription of the angle to be measured being general, and above all the letters, with any requisite remark or designation of the signal, &c.

Then the clamp at A being opened, the upper part of the instrument without the circle is turned towards the object to the right of the observer, and being pointed by the tangent screw of the same, the first angle of the series of the three verniers A, B, C may be read.

After this the clamp at D being opened, and the telescope part, together with the circle, being turned back upon the object to the left and pointed by the tangent screw at D, the first angle of the series of D, E, F will be obtained.

In this manner will the observations be continued through as many repetitions as may be desired, paying attention to conclude with the same kind of movement with which the observation has commenced, in order to give to both series the same number of angles.

In order to keep some account of the progression of the angles, it is also proper to read one vernier, for instance A and D, at each observation, and insert the readings in their proper place in the Day-Book.

From the order of progressing here indicated, the angles will successively follow the order of the divisions. If more series are observed, it may be proper to take the second series in an inverse order, or backwards on the divisions; as the influence of pressures of screws or friction, &c. would act inversely, and the indiscriminate mean correct them as far as possible.

It is also evident, that if the greatest accuracy be aimed at,

it is advisable to take two series, like the simple angles in the two-feet theodolite, with the telescope in a direct and in a reversed position, in order to compensate the influence of the verticality of the telescope; though near the horizon this influence is very small. In like manner also, the instrument may be placed in the three possible positions of the legs upon their cones, and such series may be taken at each position.

All these changes would undoubtedly contribute to accuracy, by the compensation which they would give to the indiscriminate mean of the proper number of series. It might be asserted that these changes with series of only a smaller number of angles would be preferable to long series in one position.

What has been said upon this subject relative to the two-feet theodolite, refers evidently to this instrument, as it is grounded upon the same principles, the multiplication of the angles excepted, which, in using it according to such a system, would be considered merely as a compensation for the greater diameter of the instrument. I shall not enter here into further details on this subject, as I never had time or opportunity to test these instruments completely. I measured only some angles by way of trial, the coincidence of which with those of the two-feet theodolite was very satisfactory.

Method of Observing Vertical Angles with the Repeating Theodolite.

When the instrument has been carefully adjusted and levelled in all respects, the observation of a series of zenith distances with it is taken nearly in the same manner as with the repeating circle; but in respect to its order in the use of the

clamps, it admits two different successions, differing only in the ease with which the screws come to the hand in each motion.

The observation can evidently be made by one person alone, as the level requires no particular attendance. It may however be observed from time to time, to be sure that the instrument has not been disturbed.

The following order will bring the screws so as to be always convenient to the hand of the observer.

1. Place the vernier Z on 0° or any division, and read Z and Y. These readings are written in the third and fourth columns of the Day-Book.

2. The clamp at X being loose, make the first observation by the motion of the telescope alone, and point by means of the tangent screw of the same vernier Z. When the object observed is a celestial body, the time of this observation is observed, and written before the readings of Z and Y, in the first column of the Day-Book.

3. Then W and X are read off, and written in the fifth and sixth columns of the Day-Book, one line farther down than the Z and Y have been written.

4. Unclamp the circle at Z, turn the upper part of the instrument one half a circumference round horizontally, and the telescope together with the circle through the zenith again to the object to be observed, upon which, the clamp at Z being again fastened, the pointing is effected by the tangent screw of the same Z, and the time observed is written in the first column opposite to the foregoing readings. By this, the first angle of the series by Z will be obtained.

5. Turning the instrument a semicircumference horizontally, and after unclamping the vernier X, also the telescope alone without the circle through the zenith to the object to be observed, the pointing is again performed by the tangent screw of the same vernier X, whereby the first angle of the second series, or by W, X, is obtained, and the time observed is written again in the first column.

6. The observer may proceed in this order, and in the

same manner as with the repeating circle, by a succession of the above alternating motions, until the desired series is obtained, ending at last with the same motion with which the series was begun, as here by a pointing with the tangent screw at X.

7. All the times of such a series, except the last, will belong to the series of Z and Y, and all times, excepting the first, to the series of the reading, W, X.

If several series of the same zenith distance of a terrestrial object should be desired, for the sake of great accuracy, it would be advisable to take these series in the two different manners which the instrument admits, and to use the indiscriminate mean in preference to either.

The manner of taking out the results of such a series of observations, and of calculating them, is of course exactly the same as in the repeating circle with two telescopes; and the mode of registering the observations and the results in the day-books and journals may therefore be omitted here, as sufficiently obvious.

It is evident that the method of observing time described in the repeating circle, applies also to this instrument with equal advantage and ease.

Besides this, the ease with which the light vertical circle, or the telescope alone, moves upon the transit axis, affords, in the present case, another method,—viz. to measure double altitudes by reflection on a mercury horizon, the level showing the stability of the instrument, which for this kind of observation needs no inversion or movement in azimuth, except for the small progress of the celestial body during the observation.

By alternating the motions of the transit, with and without the circle, between the direct object and its image in the mercury horizon, a series of observations of double altitudes may be obtained with great celerity; and if the sun should be the object, the limbs may be alternated, as in another observation. The times of the two series will follow exactly as in the series for the zenith distances; and all other direc-

tions given for these apply equally to the series of double altitudes. An observer, with a little experience, will be able to make such an observation without further direction. All that is desirable for it is a large mercury horizon, in order to have no need of moving it during the observation.

It is easy to adapt to this instrument a stopping arrangement for finding stars by night. These may be very light, and removeable, when not needed. On this occasion, I may remark that it is proper to make the touches of these stops light springs, and not solid parts, that in case they should come to touch, the telescope or other part of the instrument stopped, may not be affected by it.

Description of the Repeating Circle of Reflection.

The application of the principle of reflection from plane mirrors has produced the instrument which has most contributed to the advancement of nautical astronomy and geography.

When the mirrors are perfect, the accuracy which may be obtained in the measurement of vertical angles observed by means of the mercurial horizon, is certainly far superior to that from any other instrument of equal size, in which the level or plumb line is used, the circumstances in all other respects being the same.

The use of a circle, instead of a sextant or octant, introduced by Tobias Meyer, has in this, as in all other instruments, freed the results from the influence of eccentricity; and the improvements of it by Borda have furnished the means of correcting the errors of the glasses and adding the property of repetition.

In multiplying instruments, the constant parallelism of the

motions is one of the principal properties required, as stated before.

This is evidently to be applied in this instrument to the plane of reflection, which is itself determined by the position of the large mirror.

In Borda's construction, the axis upon which the mirror revolves being short, the plane of reflection is too much guided by the plane of the limb, which artists well know can not be executed with the same accuracy and ease as the axis. From this cause, the English artists abandoned the principle of repetition; and Mr. Troughton gave to the circle a construction, in which the motion of the mirror is determined by a longer axis, and the eccentricity corrected by three readings; without repeating which, from the excellence of his work, and his great care in the choice of the mirrors, has given most excellent results.

Reflecting instruments being indispensable in the survey of the coast, for the observations, to determine soundings, and others to be made on board of vessels, &c., I considered it proper again to turn my thoughts to the improvement of this instrument, as I had done long before, so as to preserve both the multiplying principle and the stability of the plane of reflection. I considered the circle itself as of minor influence, and therefore allowed it to be moveable, and alternately clamped to the solid part of the instrument, which bears the small mirror and the telescope, or to the alhidade of the large mirror, and moving with it.

Having made a description of such an instrument with a drawing of full size, before I left the country, I presented it to Mr. Troughton, who said immediately that he would make me one upon the same principles, though different in shape, as he wished the instrument to be lighter. He showed me at the same time the ideas of Mr. Mendoza, which had completely failed in a similar attempt, and of which I then obtained the first information.

Mr. Troughton gave to the instrument a shape similar to that of his reflecting circle, from which my drawing differed

in many respects; but here I had the reason, as in the other instruments, to leave him at full liberty in this respect.

I may therefore be allowed here again to suppose the construction of Mr. Troughton's reflecting circle fully known, and describe only the alterations made to it, to give it the repeating property.

Plate IX. fig. 1 is a perspective view, and fig. 10 a section of the centre part of the instrument. The parts *a*, *b*, *c*, *d*, *e*, form the frame of the instrument, which contains in the centre piece *e* the axis both of the mirror and the circle; in *a*, the support of the telescope, which may be lowered or elevated for the equalisation of the illumination of the two objects, in the same manner as in Mr. Troughton's circle; in *c*, the small mirror is fixed, exactly in the same manner as are also the handles *f*, *f*, and the rectangular piece *g*, reaching over the large mirror to receive the straight handle; but the frame reaches only so far as to unite all the above parts.

The circle itself revolves on the side of the frame opposite to the mirror, by a bell metal socket *t*, *t* of half an inch in length, upon an axis turned to the brass centre piece *e* of the frame, through the middle of which the axis of the great mirror *s*, *s* passes, as far as the upper part where the mirror is fastened to it.

The alhidade AB of the great mirror is at the end of the axis, opposite to it, and revolves upon the circle so as to read upon the divisions.

The alhidade DC is fixed to the frame of the instrument, between it and the circle, and forms two diametrically opposite readings upon the circle, for the motion of the mirror and the circle together.

The two axes have therefore entirely independent revolutions, the mirror within, and the circle without the piece *u*, *u*. The clamps of the two motions are here both outside of the circle, as it is not necessary that they cross each other in the observation. Both alhidades will give a separate series of angles, corrected for eccentricity by the two opposite readings.

When the mirrors are parallel, the alhidade AB stands under the telescope, and the alhidade DC is at right angles with it, so that in the observations, the vernier A comes alternately on the two sides of the telescope. The angle between the collimation line of the telescope, and that from the centre to the small mirror, form an angle of about 17° at the small mirror. The direction of the handles *f*, *f* is perpendicular to the collimation line of the telescope.

As all angles are measured at least double, namely on both sides of the parallelisms, the circle is divided like every other into 360°.

To give to the great mirror the full field of reflection, on the side of the telescope, when large angles are measured, the telescope is not screwed fast in the support at *n*, but the part commonly made to adjust the collimation line parallel to the plane of reflection is here extended into a tube *m* about four inches long, in which the telescope is slided in and out according to what the angle may admit, and to keep the circle not farther from the eye than necessary.

On account of the ease of holding it, the screw *l* in the telescope tube slides in the slit of this tube, to prevent it from turning and thereby altering the direction of the collimation line towards the plane of reflection.

The different eye pieces are fitted in a separate tube which unscrews at *p*, for the ease of packing.

To give to this instrument the same advantage in finding stars by night, as the circles of eighteen inches have, there is a light divided semicircle *o*, *o* adapted to the alhidade DC, supported in the middle by a small piece reaching to the telescope *a*. Upon this two sliding pieces *q*, *q* are placed on both sides of the middle, to the proper double altitude of the star, and the light pieces *r*, *r* fastened to the other alhidade at A will be arrested by them, whether this alhidade moves alone or with the circle.

The other parts of the instrument being exactly similar to Mr. Troughton's circle, need not here be mentioned. It is also evident that the construction and shape of this instru-

ment may be varied in different manners, without altering its principal qualities. I made various plans; but it would be needless to state here their varieties.

Method of Observing with the Repeating Reflecting Circle.

The adjustments of this instrument being of course in every respect the same as the well known adjustments of any reflecting instrument, must not be repeated here. In all repeating instruments, attention is required, to avoid mistaking in the regular course of alternating observations, and use of clamps and screws. It is therefore necessary to proceed at first with measured and cautious steps, and to form a regular habit of an order easy in the manipulation, which, when it becomes habitual, will always proceed more surely and rapidly. The examples of observations given in the exemplar of the Day-Book and Journal will prove that two series of ten altitudes may be taken in the space of five or six minutes.

The correspondence of observations with this instrument and others with the eighteen inch repeating circle, which I had an opportunity of making at the northern boundary line, proved that the former was capable of giving an accuracy nearly as great as the latter.

The most convenient order of proceeding in a repeated double series of observations is the following:—

1. Place the vernier A upon 0° or any desired or round number; and read off B.

2. Write these readings in the third and fourth columns of the Day-Book. (Vide Exemplar.)

3. The alhidade DC being unclamped, make an observation, by the motion of the mirror and circle together, the con-

tact being made by the tangent screw at C, when this has been clamped. The time of this observation is written in the first column, before the readings of A and B.

4. Read the verniers C, D, and write the result in the fifth and sixth columns of the Day-Book, one line lower down than the foregoing.

5. If a night observation, place the stop *q* on the light circle near the outside of the projecting piece *r* of the alhidade A, leaving it some freedom of motion, and the other piece *q* upon the opposite side of the parallelism, upon the same number of degrees, &c.

6. Invert the instrument, either from right to left, when in a vertical observation, or upside down in other positions, and unclamping the alhidade of A & B, move it up to the opposite stop on the small circle, or in general near the place which will be indicated by the reading on the small circle, and after clamping there, make again an observation, bringing the objects in contact by the tangent screw at A.

7. The time corresponding to this observation being observed, it is written in the first column below the former time, and opposite to the second reading.

8. If the stand of the alhidade of A & B is now read off, a result is obtained of the first angle of this series, to which the two times observed would correspond; and in a vertical observation on the mercury horizon, the angle indicated would be the double altitude corresponding to the mean of the two times.

9. Invert the instrument again, to bring it in the same position as for the first observation, unclamp the alhidade C, D and move the circle with the large mirror, (the alhidade of which remains clamped to it) near to the first position or place of the stop, where C is again clamped.

10. In this position, make again an observation effecting the contact by the tangent screw at C, and writing the time under the second time.

11. In reading the verniers C & D, the first angle of the

series would be obtained, giving again directly the double altitude corresponding to the mean of two last times, if the observation is a vertical one on a mercury horizon.

12. To continue the series farther, the next operation will be the moving of the alhidade A, or the mirror alone, as in No. 6, and the alternation may be continued as far as desired; the last observation being always one of the same kind as that first made, in order to give to both series the same number of angles.

13. The times belonging to the first series A & B will be all the times observed, except the last; and the times of the series C & D, all the times except the first, as in the repeating circle with two telescopes, and the calculation of each series will be separate.

If the angle observed should increase during the observation, as in observing time for instance, it will be proper to attend occasionally to the stops, that they may not be too near, so as to occasion them to be touched by the alhidade, and disturb the readings. In observing the sun, these stops are best removed to the end of the circle.

In keeping fast the clamp of the alhidade C, which holds the circle, and moving only the mirror, the instrument will perform exactly the same functions as Mr. Troughton's circle, by the single cross observation; and in determining the point of parallelism of the mirrors, the same observations may be made as with a sextant; but in these the instrument loses not only its peculiar advantages, but even would not serve so well as a sextant, which is lighter, and its parts purposely calculated for solidity in this kind of observations.

If in terrestrial angles, the two objects observed should be equally well illuminated, so that the equalisation of light could be made constant, the alternation of the angles can be effected without inverting the instrument, by changing alternately the object to be viewed directly; by which the other will be brought to alternate equally with the position of the mirror, to receive the reflection; and the inconvenient position of the hand, or the change of handles, is avoided.

Description of the Plane Table, and the Alhidade to the same.

The best method of surveying the minute details which are to fill up a triangulation, is undoubtedly by the plane table and its alhidade, with a telescope revolving in the vertical. This method will give to the detail surveyor the full result of the triangulation with respect to the relative position and distances of the points to be determined, in a mechanical form, appropriated to the nature of his work; and which will not only be a guide and reference, but also a means of enabling him to determine his distances, and to verify his work constantly as he proceeds, and by reviewing the fundamental points, to discover an error immediately, before it may mislead him. The detail surveyor can therefore proceed with confidence and celerity, and his work will be greatly diminished by this method, as well as by saving all the work commonly called plotting, (necessary in all other methods,) which besides introduces new errors, while those made in the field remain concealed until it is too late to correct them properly.

The plan of the triangulation being properly adapted, will besides be made at once sufficiently by the mere projection of the triangulation, as will be observed in its proper place. The details being introduced in the field, immediately under the eye, will be much more numerous, more accurate, and natural; so that to a man acquainted with the subject, it will be easy to distinguish details and plans surveyed by this method from those taken by the theodolite or the needle. The last of these instruments is the worst that can be employed for the purpose, and has probably been transferred to land only from its use at sea. As a historical proof of these assertions, I shall only mention that the plane table has been used in the surveys made in East India by the East India Company,

under the direction of a German, and on account of the advantages for which I gave it the preference in this work.

The principles of the alhidade are simple. It may be accurately constructed, and easily verified. Its properties should be :—

1. To level a plane.

2. To describe an exact vertical upon this plane.

3. To draw, or rather indicate, upon this horizontal plane a line parallel to the vertical plane of an object.

All further complications are not only useless, but always prejudicial to the accuracy of some of its main properties, particularly in applications similar to those intended in this work.

In Plate IX. fig. 2, 3, & 4, *a*, *b* is a rule of about sixteen inches long, three inches broad, and one-tenth of an inch thick. Four pillars *c*, *c*, near its middle, rise about three inches high. They support a frame *d*, *d* perpendicularly across the rule, about six inches long. Upon the two ends of this arise perpendicularly two uprights *e*, *e* of four and a half inches in height, forming the supports of the axis of the telescope.

The telescope *f*, *g* is a regular small transit, describing an exact vertical upon the horizontal axis *h*, *h* without clamping, stop circle, or any similar contrivance. It is about fifteen inches long, and of about an inch and a quarter aperture. It slides forwards and backwards in a tube *l*, *l* of four inches in length, fixed to the square centre piece, and may, by that means, be placed in equilibrium, so as to remain in all positions by the mere friction of the axis in its supports, and the level hooks.

In one of the supports is the adjustment for levelling the axis of the telescope, by a capstan head screw *i*, *i*. There is expressly no horizontal adjustment for this axis, to effect the parallelism of the vertical plane of the telescope with the sides of the rule, because this is intended to be fixed and adjusted by the proper filing of the Y's in the supports, or the placing of the frame *d*, *d* on the columns *c*, *c*.

Before the object end of the telescope there is a light lengthening tube of three inches in length, to keep the side light and glare from the object glass, which is very necessary in this instrument.

The eye part of the telescope is in a long tube sliding in the main tube. By sliding it in and out, the wires are placed in the focus of the object glass ; and by turning it in the tube they are placed perpendicular.

There are three vertical and one horizontal wires. The multiplication of the vertical wires is for the observations of transits of celestial bodies in observing transits, by which a survey may be properly oriented, or a true meridian drawn in it. The eye pieces may be chosen at the pleasure of the observer, and, in respect to their magnifying power, they must be adapted to the middle distance of the objects which may come under observation. It is therefore proper to have several changes ; and it will be very convenient to have one prismatic, which being placed so as to look upwards, will serve for objects at such an elevation as will not easily allow room for the head between the plane of the table and the eye piece ; and it would not be proper to give to the instrument too great an elevation in its construction, because it would affect the stability of the vertical plane of the telescope.

The spirit level *k* hangs to the axis by hooks, and has proper adjustments. It serves for the levelling of the axis of the telescope, and the plane table itself. The method of using it is too evident and simple to be detailed here.

As this instrument will, in its use, be placed on different parts of the plane table, it becomes a desirable object that it should be as light as may be consistent with its necessary solidity, in order that it may not affect the level of the plane table. For this purpose, the large rule is cut out as seen in fig. 2, so as to form only a skeleton to the outer straight line, and the supports of the telescope. In like manner, the frame *d*, *d* and the supports *e*, *e* are cut out, so that the in-

strument is rendered very light, and at the same time very solid, by the nature of its framing.

It may be useful to give here the description of an addition which this instrument admits, and by which it answers the purpose of a very good goniometer.

In the middle, between the pillars *c*, *c*, is a socket which receives an axis of at least one inch in length and about one-third of an inch in diameter. At both ends of the rule, *a* & *b*, there are two very thin pieces, either added to the end edges, or worked out in it, in which two points are made, at equal distances from the centre, and diametrically opposite to each other.

Another rule similar to the above, and of equal breadth and length, is kept from bending below by an edge bar tapering from the centre towards the two ends. This has in its middle the steel axis to the socket of the other rule, which is put upon it, and held by a screw from above, when the instrument is to be used as a goniometer.

In the middle, below the rule, is a centre piece, either square or round, with a screw sufficiently solid to hold well, and adaptable to any stand, which will of course be conveniently contrived so as to suit the motion work of the plane table. This table will be described hereafter.

A decimal scale will then be constructed on the radius of the instrument considered as a unit, which therefore may be chosen so as to serve at the same time as a scale for the plane table operations. The cords must be measured by a beam compass of proper length, &c. The numbers on the scale may be marked at one half their value, so that when the cord measured by the beam compass is applied to it, they will immediately indicate the size of half the angle, which being taken from a table of natural sines, will give the angles with great ease, and, if proper care is taken, with considerable accuracy.

The levelling, and all adjustments of this instrument, are of course exactly the same as when used on the plane table.

The measuring of the angles can of course be varied, and the cords of the two vertical angles can always be measured, and in many cases the supplements. It will be more proper to let every angle be composed of two, given by the cords of two angles, going off from a fixed position of the lower rule, than to place the lower rule together with the upper upon a point, with their points placed upon each other.

Instruments such as I have now described at length, I had executed in 1792, by the exact artist Develey in Lausanne in Switzerland, for the Surveyors of the Comissariat General of Berne, as we were not satisfied with the usual alhidades with lights. These instruments have, in all respects, answered very well, and have not deteriorated by long use.

The plane table itself ought to be about thirty inches by twenty-four in size, as light as it can be made consistently with solidity. It may, on that account, be proper to have it pannelled. I have always found that old pine board, which had served long as doors or house furniture, &c. was the best material for it. The size above mentioned allows papers of such dimension as will be found advantageous, while a small table will introduce inaccuracy, by the necessity of changing often, and adjusting many papers. For the same reasons plane tables, with frames to stretch the paper upon, are to be rejected. The paper must be allowed to be of great length; and a breadth of three feet and a half may well be placed on the table, of thirty inches in one direction. It is good to have the edges rounded off, so that when the paper is wound round it, the part not used may be rolled up under the table, and kept from folds or bends.

The paper is stretched and held upon this table by brass, or (which is still better) steel springs of sufficient strength, and of the shape and about the size seen in Plate IX. fig. 6 & 7. These springs sliding over the edges of the table, and holding in front, admit freedom to the paper around the table, by the greater width of the round spring part behind.

The motion work of the plane table is exactly similar to that of the large needles, and may be seen in Plate IX. fig. 5.

Instead of the pillars *d*, *d*, which carry the needle, there are three screws, by which the uppermost circular piece *n*, *n* is screwed fast to the middle of the plane table, which has for that purpose a circular part, giving an additional thickness to the table in this place.

The piece *n*, *n* is a strong circular rim, eight inches in diameter, with six strong radii. The outer part has a bell metal ring, upon which it revolves upon the lower plate *l*, *l*, to give a smoother motion than brass on brass. In the centre *m* is a bell metal axis, about three inches and a half long, passing through the centre of the piece *l*, *l*. The piece *l*, *l* is similar to the above in shape, only stronger, and projecting somewhat over it, so as to admit the clamping part *p*, which goes in a small rim cut in it all round, and by which the plane table is placed in the proper direction by a tangent screw, after being approximately placed by hand.

In the centre piece *l*, *l* is a strong piece *o*, *o*, through which the axis of the upper plate passes, and in which its revolution may be fully stopped by the milled head mother screw *t*. This centre piece has a small neck at *o*, *o*, below which it is formed in a part of a sphere of about an inch and a half in diameter, which is held down to the lower piece *r*, *r* by the sections of a hollow spherical piece *q*, *q*, covering the above part of a sphere.

In the plate *r*, *r*, which is again formed like the others, but made the strongest of the three, (the rim being about an inch and a half broad and one-third of an inch thick,) there are three perpendicular screws *e*, at one hundred and twenty degrees distance from each other, supporting the piece *l*, *l* upon round nobs, and being turned by their milled heads below the plate, which fall exactly in the middle between the three sockets *s*. These sockets receive the joints of the brass ferrules *a*, which move round the pin passing through them, and have a strong wood screw inside, in which wooden legs five feet long are screwed fast, and extend far enough out in all situations of the ground, in order to give sufficient solidity to the table. These legs have iron ferrules and points below.

At about two-thirds of their length from below, they are near two inches thick, tapering gradually and equally out on both sides; so that the lowest end becomes the smallest, and is reduced to about one inch. This form of the legs adds considerably to their strength, and prevents them from bending.

Of these alhidades and the motion works for the plane tables, I had only two constructed in England, though in the farther progress of the work a greater number of them would be required. These, however, might be made in this country, using those constructed in England as models.

Description of the Magnetic Needles.

In the survey of a sea coast to which ships come under the guidance of the magnet, it was of course of interest to observe the variation of the needle, to obtain data for this interesting element.

For this purpose, and not with any view to its use in the actual survey, two needles were constructed; and I intended to join to the observations of the variation, those of the oscillation, and for which I had a needle of my own. They are constructed exactly on the same principle as the one I had constructed in 1801, by M. Esser, Mathematical Instrument Maker at Arau in Switzerland.

Plate IX. fig. 5, is a vertical section of this instrument, which may suffice to explain its construction. The needle z, z one foot in length, is in a circular box about an inch high, having an horizontal circle x, x silvered, and divided to every twenty minutes. A small silver vernier on the needle assists in reading the subdivisions (which might however have been carried farther on the circle itself.) The circle is divided as usual into 360°, beginning from a radius parallel

to the telescope. The glass cover rests on three points, and is held to them by the spring of a brass ring above.

The needle *x*, *x* hangs edgeways, has a jewelled cap mounted in brass, which can be screwed in the centre from both sides, to verify and compensate the parallelism of the magnetic line of the needle with the middle line of its figure, which serves for the readings.

Four pieces are adapted outside of the needle box, projecting a little above it, to receive a large spirit level across the box, in two situations, at right angles to each other, one parallel to the telescope, the other parallel to the axis,—by which the instrument is levelled.

The needle box has below two strong pieces *b*, *b* diametrically opposite to each other. These form the sockets of the horizontal axis *y*, *c* of the telescope, bearing at its thicker side *c* the piece *h*, in which a tube of four inches long is fastened. Through this tube passes a telescope, in all respects exactly equal to that of the plane table alhidade, so that they might be interchanged in case of accident.

This telescope describes a complete vertical circle, to which it is of course adjustable by the motion of the wires, and it was not found proper to give it any other adjustment. Its verticality is best verified by the reflection in a mercury horizon of the pole star, or any other object seen under a large vertical angle, when the instrument is adjusted by the level. The correction is of course to be made, if necessary, half by the wires, and half by the supports of the level. The needle itself is then equilibrated for this adjustment by the brass counterpoise *f*. The adjustments are so simple, easy, and apparent, as to need no description.

The needle is prevented from moving by a stop, when not in use.

The needle case with all the above rests upon six pillars *d*, *d*, by which it is made fast to the plate *n*, *n* which is the first of the stand part of the instrument. All the lower parts being exactly equal to those of the plane table, I shall refer to the description of that instrument for further details.

In making an observation, the needle box revolves by the rims at *n* upon the plate *l*, *l*, and is clamped, and the telescope pointed, by the clamping and tangent screw at *p*. If the sun or a star is observed, the transits of the three wires are observed as in any other azimuth, and the time accurately noted, and determined by other observations.

When a magnetic azimuth has been observed, and read off at both ends of the needle, with the telescope on one side of the box, suppose to the right hand, then the needle must be turned a semicircle in the azimuth, and the telescope as much in the vertical, and the observation repeated again, exactly as in the observations with the two feet theodolite.

The indiscriminate mean of these two observations, with their four readings, must be taken for the result, as it will be corrected for the eccentricity of the needle, and the eccentric position of the telescope.

A more minute description of the operations will not be necessary. The inversion just mentioned ought never to be neglected in any use of the magnetic needle whatever, as no reliance can be placed in the results without it.

It may be proper to observe that it is necessary to pay great attention to obtain what is called free brass for the construction of all instruments in which the magnetic needle is used. All castings from brass filings or borings contain more or less iron, which will act upon the needle.

With a view to have the needle as little affected as possible, I requested that the body of the azimuth compasses under consideration should be made of pure copper. But such was not to be obtained; as in England the copper in commerce is made by a precipitation from a copper solution by means of iron. By this process, it is always mixed with iron, and therefore rendered unfit for the use intended. I was therefore lead to the use of free brass, as just stated.

Peculiarities of the Five Feet Transit Instruments destined for the Observatories.

The axes of the transits are generally made of considerable length; but there is probably more lost by this in solidity than can be gained by the nicety of the adjustments.

In each of the transit instruments made by Mr. Troughton for the two observatories which were intended to be built, the axis is thirty-three inches long between the supports. The two truncated cones which form it meet in the middle upon a spherical piece about nine inches in diameter, which receives also the two parts of the telescope; exactly in the same manner in all respects as the transit telescope of the two-feet theodolite.

The bell metal ends of the axis, which are about three quarters of an inch in diameter and one inch and a quarter in length, rest on supports which are screwed to the flat top of the stone pillars, the transit not being hung to the inner side of the pillars, as was formerly the custom. They are of the following form:—

In Plate IX. fig. 8 & 9, *a*, *a*, *a*, *a* is a plate of brass about half an inch thick and six inches and a half square. Four strong screws *b*, *b*, *b*, *b*, fastened in the top of the stone by gypsum, receive it, and it is secured by four mother screws pressing it close to the stone.

In the middle of this plate is elevated at right angles a strong piece *c*, *c*, about three inches high and one inch thick, in the shape of a bridge, which slides in a runner, cut in the plate parallel to the telescope. This piece being moved by means of the screw *e*, *e*, will adjust the telescope to the meridian. In the uppermost part of this piece is the rectangular incision, forming the Y's upon which the axis revolves. Below it, this piece is cut out in the form of a segment of a circle, which is subtended by a perpendicular screw in the mid-

dle *d*, which can be moved by its milled head, and presses with its lower part against the cord part of the same piece below; the upper screws in the bridge thus forcing its middle up or relaxing it by the mere spring of the metal. This is all the adjustment which is allowed to the supports, as it is supposed that the stone pillars, and therefore the plates, may be brought within these limits by previous levelling, and thereby greater stability be obtained.

About five inches from both ends of the axis, are two strong rings, of about four inches diameter, turned exactly on their edges. These turn upon perpendicular rollers of the same diameter, which are pressed against them from below, instead of counterpoises, by means of springs enclosed in circular boxes, about eight inches long, which press upwards the square slide bearing the rollers. The springs are moderated from below, by a screw at the lower end of the cylinder. These counterpoising arrangements are fastened to the inner sides of the pillars, in the same manner that the pans of the transits rising between the pillars usually are.

There is neither semicircle, nor alhidade, nor clamp of any kind, to keep the transit in a certain position; as all arrangements of that kind are very apt to disturb the verticality or accuracy of the circle described by the transit; which induced Dr. Maskeline to remove them from the transit of the Greenwich Observatory, and to substitute in their place an optical arrangement.

In these transits the pointing in altitude is performed by two semicircles, one on each side of the eye piece, on which levels move by friction, around their centre, with verniers and all proper adjustments. These circles are numbered, so as to show altitudes, as they could not be adjusted to declinations or polar distances, on account of the unknown latitudes of the future observatories. The verniers being therefore placed upon the proper altitude, the telescope is turned upon its axis until the level is horizontal, when the star intended to be pointed at will appear in the telescope,—one

semicircle serving north of the zenith, and the other south of it.

The level for the axis of the transit is a free level hanging between the pillars, and has a tube of upwards of an inch in diameter.

The illumination is through the axis, by a lantern placed on one of the stone pillars.

To see the meridian mark distinctly and without parallax, in case of its being somewhat near, (as the nice adjustment will not permit us to alter the focus from the infinite distance) it has been usual to adapt before the object glass another glass of the focal distance equal to the distance of the mark. I considered this method liable to some objections, and besides could not know the distances of the future meridian marks.

I suggested therefore the following simple arrangement, the correctness of which I had long ago tried, and which obtained the approbation of Mr. Troughton. A brass plate is screwed to the end of the additional tube placed before the object glass, having in its centre a hole of not more than half an inch in diameter through which only the middle rays of light are admitted. Thus all parallax is avoided, the image is exceedingly well defined, and the great loss of light which naturally takes place is of no importance.

As these transits are not within my reach, it would be improper to enter into a more minute description of them. This task is left for the astronomer to whose care they shall be committed.

On the Astronomical Clocks intended for the Observatories.

About a year before I came to London, a new clock had been put up in the Royal Observatory of Greenwich, to serve

with the mural circle which Mr. Troughton was then making. Dr. Pond gave me the most favourable account of this clock. He told me it never deviated from true time more than half a second; and accordingly I considered it proper to have the clocks for the intended observatories made by the same artist, and upon the same principles; as it is difficult to get a very good clock, and the prices asked are proportionally far above those of chronometers. A greater number of the latter are constructed on account of their constant use in the navy and naval commerce, which forms in England the principal support of this branch of the arts, as well as of the mathematical instrument making.

The clocks were therefore constructed by the same artist, Mr. William Hardy from Scotland, residing in London, and who is eminent for various valuable inventions in the line of clock and chronometer making, and for the very superior execution of all his works. The scapement, as well as the arrangement of the wheelwork, is of his invention, and exactly similar to the clock of the Greenwich Observatory, with only some small differences which I suggested, in order to augment the stability, and facilitate the reading upon the dial.

As I have not access to these clocks at present, I cannot give as full a description as might be desirable. I must therefore confine myself to observing, that each of them consists of four wheels, and has the hour wheel of about four inches in diameter in the backward motion of the drum, carrying a plate which shows the hour through the dial plate. It may however be useful to describe the scapement from the drawing which I made of it in London, as I know of no description either of it or of the other peculiarities of Mr. Hardy's clocks.

In Plate VI. fig. 8, 9, 10, 11, *a*, *a*, *a* is the scapement wheel, with thirty teeth. The pinions go on jewels. It stands beyond the hind plate of the clock *b*, *b*. Its outer pinion goes in the bridge *c*, *c* projecting from the back plate, the

arbor going through the clock to bring its other pinion in the front plate of the clock.

A strong piece of brass *d* is adapted to the plate *b*, projecting a triangular piece *e* directly over the scapement wheel. It receives on each side two steel springs *m*, *m* & *n*, *n*. These are held fast to the piece *e* by the lower screws *g*, *g*; and by means of the upper screws *f*, *f* they can be adjusted to more or less pressure in their lower parts. These form the sloping and impelling part of the scapement, which is therefore regulated by them.

All the four springs have circular holes, at exactly equal height, immediately below the triangular piece *e*, and between the two strengthening rims *h*, *h*, where they are weakened so much, as to present only a very light spring in their action upon the scapement wheel.

At that place also, the springs are bent, so as to make them tangents to the scapement wheel.

Each of the springs *n*, *n* bears at *i* a ruby mounted in brass, and adjustable by the small screws *k*, *k*, projecting from the spring towards the clock, over the scapement wheel, which is stopped by their falling alternately within the circumference of the wheel upon a tooth, when they are not supported by the pendulum in its motion. These rubies stand ten teeth and a half distant from each other. The distance which they are allowed to fall is regulated by two screws *l*, *l*, going through strong arms reaching up from the bridge *c*. The screw *l* is screwed in or out, as the adjustment of the fall of this spring may require. At the end of the springs are light brass pins *o*, *o*, projecting outwards over the pendulum *s*, to meet the inclined planes *p*, *p* at the two ends of the cross bar of the pendulum. By this the springs are alternately lifted to disengage the scapement wheel.

The two springs *m*, *m* bear, at the distance of one tooth farther on each side, each an inclined plane or pallet *q*, *q*, which are jewelled, and by means of which the springs are alternately lifted by the teeth of the scapement wheel, when this slides under them, after being unstopped; so that on

the side at which the wheel is stopped, the tooth is at the top of the inclined plane, and on the side where the top falls between two teeth, a tooth stands below the inclined plane. These two springs have also at their end, each a light brass pin *r*, *r* reaching to the same inclined planes *p*, *p*, which terminate the cross bar of the pendulum. This inclined plane or pallet meets these pins exactly when the stop *i* is disengaged and the oscillation of the pendulum is completed, and the pins press upon it by the strength of the returning spring, to give to the pendulum the necessary impulse after each oscillation. This impulse is moderated by the screws *f*, *f*, and the inclined plane returns, by the same power of the spring, into such a position between two teeth, as brings the screw which is more distant exactly at its lower end.

The succession of these motions, alternating between the two sides, forms the scapement. Their equality, and coincidence with the motion of the pendulum, is adjustable by a small horizontal movement of the bar *p*, *p* upon the pendulum, which is directed by a short arm or tooth *z*, turning upon the pendulum by means of a key, and fitting in an indenture of this bar. The motion is stopped by the pressing screw *y* in the middle of the cross bar, the hole being somewhat elongated, to admit a small horizontal motion.

The pendulum *s*, *s* is suspended from a strong brass bar *u*, *u* passing over the upper ends of both plates of the clock, and supported (agreeably to my suggestion) outside of the pendulum, by a strong square pillar *t*, which stands under it and is screwed below to the same strong brass plate upon which the clock itself is screwed fast.

The spring *v*, which forms the suspension of the pendulum, is mounted in a brass piece *w*, sliding in a slit of the bar *u*, and there kept in its proper place by a steel pin crossing over the piece *u*, *u*. The pendulum rod is adapted to the spring by a steel pin *x*, crossing both.

To determine the centre of oscillation in the suspending spring *v*, this is again perforated, the horizontal diameter of the round hole being exactly in the same horizontal plane

with the horizontal diameter of the four holes of the springs, in order that the motion of the pendulum and the spring may go off as from one axis, to avoid all friction in the touching of the pins *r* and *o* upon the inclined plane *p*.

The pendulum rod itself is a parallelopipedon of steel, one-third of an inch broad and one-tenth of an inch thick. The compensation for temperature is made by a mercury column about seven inches high, and 1.9 inches in diameter, included in a glass cylinder, which serves as the lens of the pendulum. It is therefore adjustable by experiment, and completely at the disposal of the observer, and for any latitude. There is also a screw at the end of the bar, by which this arrangement is suspended to it, and by which the length of the pendulum itself is adjustable.

This pendulum is well known by the name of the Mercury Compensation Pendulum; and it is evident that it was the only one adapted to my purpose, as I was uncertain in what latitude the observatories would be built. On general principles, any compensation of a pendulum must compensate for the sum total of the effect of temperature upon the going of the clock, and not merely for the expansion of the rod itself. It must therefore be determined by experience and observation; as a rod compensating itself exactly in a pyrometer, would not for that compensate every clock; and these clocks would not be compensated by it, on account of the influence of the temperature upon the scapement springs.

The jewelling of the larger pinion holes of a clock does not appear to me to be of any advantage. The pressure upon them appears too great, and on that account occasions a grinding of the pinions. Therefore only the scapements are jewelled in these clocks. The other pinion holes are boxed with brass taken from a piece brought to England from Bengal as a sample, which was given by the Board of Longitude to Mr. Harrison, the first inventor of chronometers. At his death, Mr. Hardy bought it, and uses it with the greatest economy for such purposes. The ends *p, p* of the cross bar on the pendulum are also lined with this brass,

The dial plate is thickly plated with silver, in order to preserve well the whiteness, which facilitates the reading, while the mere silvering commonly used, soon becomes so dull as to render the reading by night or from a distance inconvenient.

With the same views—to facilitate the reading, the circle of the second hand is larger than usual, and all useless numbers are excluded, in order to give to the divisions a more striking appearance.

It was my intention to make the weight always move at some distance even, below the lens of the pendulum, to avoid the too great influence of it upon the pendulum, particularly in the proximity of the lens, as it is a well known fact, that the clock will always change its rate of going in consequence of the mutual attraction between the lens and the weight.

In clocks which go only twenty-four hours, as those described above, which are always wound up at regular times, this influence, occurring every day equally, will on the whole compensate itself, and the intermediate deviations occasioned by it will remain concealed, as the clock will always be regulated according to its mean daily rate. It appears therefore the most evident in those clocks which go a long time with one winding. On a Franklin clock, which I put up at West Point in 1808, and which shows only four hours, and went forty days with one winding, the pendulum was completely stopped when the centre of gravity of the weight was about ten inches below that of the lens, their horizontal distance being three inches and a quarter; the weight and lens both were considerably heavy.

To counteract this mutual influence, I hung a musket ball by a thin wire from the board on which the clock rested to the point where the centre of gravity of the weight was when the clock stopped, and in a few seconds it began to oscillate isochronous with the pendulum.

These two experiments I repeated several times, with exactly equal results; and though I attributed the stopping of the clock to a small defect in its position, I made the weight

to go in future below this stopping point, and I never wound it up as far as that point. This reduced its time of going, till the weight rested on the floor to fourteen days, and also destroyed the effect of the attraction of the lens and weight.

The placement of the clocks here described requires great care, attention to solidity, and various peculiar arrangements which cannot be described here. Without such arrangements, they would be spoiled immediately, and disappoint the expectations which are with reason entertained of them.

Plan of an Observatory proposed to be built in Washington.

In my plan of operation for the survey, I proposed the erection of two observatories in such places as might be found most advantageous. It seemed evident to me that the use of these establishments might be extended to objects of general scientific improvement, independent of the survey, without any considerable increase of expense; and my views on this subject were supported by the approbation of many eminent men in public life.

When I rendered in the accounts of my mission for the instruments in June 1816, the President, Mr. Madison, as well as the Secretary of the Treasury, Mr. Dallas, were as desirous as I was, that this part of my plan might receive its immediate execution. I thought it important that one of these observatories should be located at the seat of government; and many considerations led me to select for this purpose a part of the hill north of the Capitol, and in the centre of the city. Circumstances which it would be useless to relate here prevented the execution of this project; but still it may be proper to give the plan and description of the proposed observatory, as they are necessary to complete the subject

of these papers, and may at some future time become useful.

The present state of astronomy is averse to those vast and splendid buildings formerly erected for observatories which now stand near the smaller buildings forming the actual observatories, and obstruct their view.

I therefore thought it my duty to propose a comparatively small building, adapted to the instruments intended to be used in it, but still so formed as readily to admit of enlargement, if this should become necessary.

The principal aim in an observatory building, besides proper shelter for the instruments and convenience for their use, is the stability of the instruments themselves, so that they may be independent of the influence of any motion in the observatory itself, or in its neighbourhood. This object is obtained by founding the parts intended to support any instrument at some depth in the earth, insulating the building from the surrounding ground by a ditch, and supporting the floor of the observatory itself upon pillars separate from all other parts of the building, and particularly from the pillars that support the instruments.

The instruments for which my plan was adapted were,—a transit instrument of five feet, an astronomical clock, the eighteen inch repeating circles, and the large telescopes, and a zenith sector of six feet, ordered and yet expected of Mr. Troughton. It was also intended to make this observatory the place of deposit of the standards of weights and measures, the chronometers or any other instruments of the collection when not in use, and of an appropriate library.

Plate VIII. fig. 1, is the plan of the observatory, at the level of the floor; fig. 2 the vertical section, in the direction of the meridian, through the transit; fig. 3 the northern front; and fig. 4 the vertical section in the direction of the parallel, through the transit.

The whole building is forty-two feet in the direction of the parallel, and twenty-eight feet in the direction of the meridian. The walls are at least two feet and a half thick below

ground, and may be diminished to about one foot and a half at the top.

The south front has three windows, the east and west front each one, and the north front two. The door is in the place of the north eastern window. In the middle of each of the windows, the wall projects inward, in form of a semicircular pillar two feet in diameter, *a*, *a*, *a*, the top of which, together with the window shelf, is covered with one flat hewn stone, fastened in the wall, and three feet above the level of the floor. This admits any moveable instrument to be placed under the window for observation, even in the meridian of the transit, and the windows and shutters can be closed outside of it, without disturbing it.

The windows are all five feet broad and nine feet high in the clear, which will admit observations as near to the zenith as is otherwise practicable with moveable instruments, and give sufficient freedom in the azimuth, not only for all circum-meridian observations, but also for corresponding altitudes.

The windows and the shutters slide by counterpoises entirely below the window seat, in the recesses *b*, *b*, made for the purpose in the outside of the wall, and covered by a wooden frame projecting sufficiently to shelter them all. The covers *c*, *c* of this frame form the outer part of the window seat, and move on hinges; by which means they open or shut the recess with its frame, and support the windows and shutters, when these are closed.

The middle of the observatory is occupied by the transit, which rests upon two solid stone pillars *p*, *p* elevating it nearly seven feet above the floor. Their inner sides are perpendicular, and thirty inches from each other; the three outer sides are tapered towards the top. Their bases are about two feet square, and the tops about ten inches. Upon their flat tops the supports of the transit are fastened, and on the inner sides the counterpoising spring rollers, as has been described in the proper place, and may be seen in fig. 4.

These pillars go through the floor without touching it, and rest below upon a solid block of masonry, about six feet high, firmly founded below the excavation of the cellar on a base the breadth of which must be proportional to the solidity of the material employed, of which the best would be one solid block of stone.

Upon a similar pillar *q*, somewhat on the side, to the south east of the transit, the clock is to be placed in such a direction as to present the face about perpendicular to the desk. The centre of the second hand must be made to come about five feet eight inches above the floor, for the ease of reading and to show below the transit. It can be easily illuminated by a lantern placed on the side of the pillar near it, so as not to throw any light to the eye of the observer.

The top of the pillar is regulated by the size of the clock, and the base by the necessary solidity. It must be independent of the floor, and have a particular shape adapted to the clock. To admit the case to go round it, without enclosing the pendulum in the stone, it may rest upon the same basement as the transit, or upon a similar one equally solid ; but there must be room made in it to admit the weight of the clock, intended always to go below the floor.

The complaint against the small cuts in the roofs of observatories is well known, and their influence, in a warm climate particularly, in producing a local refraction near the observer, would be too great. This was the reason for placing the transit in the direction of the windows, which will be opened entirely for observation.

The part above the window, up to the roof, presenting itself outside like a continuation of the wall, fig. 3, *e*, *e*, must also open completely, like an inside shutter.

The roof over the transit between the two windows must slide out to both sides upon the other roof for the whole breadth of the windows. It is composed of five double shutters of strong sheet tin, moving on round iron bars *g*; *g* lying on the roof, and reaching far enough in the cut to give a solid support to the shutters ; and if small, they might go entirely

across without taking so much light from the telescope as to produce any impediment.

The easy motion of these shutters, and their close shutting, against drifting snow particularly, is an object to be attended to carefully, which cannot be described here.

The second instrument, for which a separate stand was to be prepared in the observatory, was the zenith sector. This was intended to be placed upon the conic pillar *d*, and to have a large and suitable aperture in the roof, like that for the transit. But as the zenith sector is not yet obtained, all arrangements could be merely preparatory; and they could only be well adapted when the instrument should be at hand.

When at any future time a mural circle should be added to the observatory, this was intended to take the place of the sector, and the roof between the corresponding windows to be opened as for the transit. The sector would then be removed to the corresponding situation on the other side of the transit, where now the observer's and guard rooms were placed, the partition being taken away, and an addition of one or two windows breadth being made to the east of the building to provide these necessary rooms.

The entry would still remain the same, and it must be observed, that all direct communication between the actual observatory and any other room which may be heated in winter, must be avoided.

These rooms must be placed in the east side of the building, and the fire place as much as possible towards the south-east, because the north-east wind is in this country the rainy wind, and therefore the smoke of the chimney, which would obstruct the observations, can only be brought by the wind over the observatory, when the weather would otherwise not allow the observation to be made; and with all other winds which accompany fair weather, it will be driven from the observatory so as never to be incommoding.

The floor of the observatory is supported upon separate pillars of masonry *h*, *h*, built in the cellar, and touches neither

the wall nor any of the pillars; the joints being covered with cloth nailed to the floor to prevent the draft of the air from the cellar. The under part of the floor is plaistered like a ceiling, in order to prevent more effectually the dampness, and make it a more compact body or mass.

The cellar must be about five feet deep, as well to prevent dampness under the floor and about the pillars, as to admit easy access to these, and beneath the floor, in any case of need. For the same reason also, the bull's eye windows are given to it in the southern and northern front. The access to it may be under the step which leads to the upper room, and under the main door and the bridge before it a door may be made to come into the ditch.

The ditch around the building must be at least four feet deep, and about three feet in breadth, to intercept all oscillations of the surface of the earth which may be occasioned by wagons, &c. particularly in cities or near inhabited places, roads, &c. This of course renders necessary a light bridge passing to the door.

The roof is arched, and elevated about twenty feet above the floor, to avoid all close air under any circumstances whatever.

Instruments which would reach into the upper heated air of a room would never make a good observation, particularly in such a variable climate as this.

My plan for the framing of a roof may be seen in the figure. In the arrangement of the rafters, it was necessary to pay attention to the opening in the roof that might be required for the additional instruments mentioned above.

Promiscuous Remarks upon the Principles of Construction, the Choice and Trial of Instruments.

After having described various instruments, it may not be improper to add some general observations upon the subject, which my experience has enabled me to make.

The navy, and ships employed in commerce, constitute in England the principal support of the mathematical instrument making, and have established this branch of the arts on a large scale, and contributed to its perfection in the last century, after the invention of the reflecting instruments.

The next encouragement arises from gentlemen who take a pleasure, and rationally amuse themselves in astronomical observations. These amateurs occupy the artists on instruments of larger dimensions, of greater accuracy, and more complicated and varied construction.

The use of instruments for scientific establishments come after these two in the line of influence. The instruments constructed for such purposes are, comparatively speaking, limited as to their number, and last too long to be of much consideration to those who construct them.

From this results the following state of things in relation to the instrument making in England.

The instruments suitable for naval purposes and for common surveying and levelling furnish the principal support of the artist. From the profits arising from these, he pays his workmen, and brings up his apprentices. The extent of these two branches is proved by the numbers which are put upon the instruments in regular succession.

Amateurs requiring from the artist a greater variety, and instruments of a larger size, he is enabled to extend his establishment, and to employ his workmen at a greater variety of work. This prevents their passing into the class of common mechanics, to which those are really reduced who are

confined to the making of the usual naval or surveying instruments.

The scientific instruments which the best artists alone will or can make, are improved by the establishment of the works for amateurs; and the artist obtains by them his credit and fame. But the profit on them is of little consideration; as the time and care which the artist must bestow upon them himself, to the detriment of his profitable work, renders them very expensive to him. On this account, none but artists who are in easy circumstances can execute them.

On the continent of Europe, the case is somewhat different. The navy does not of course employ as many of these establishments as in England. They are more limited in their extent, divided into a greater number of branches, and directed more to such instruments and philosophical apparatus as are used on land.

The English establishments of this nature having towards the end of the last century surpassed those of the continent of Europe, they have frequently supplied the latter with instruments of various descriptions. But the improvements to which science has given rise on the continent, the delays occasioned by the distance, and the separation occasioned by the events of the last twenty-eight years, have established this branch of the arts again on the European continent, in the hands of various artists, and on a new and well principled foundation.

The frames of instruments made on the continent are generally cast in one single piece, and filed by manual labour. Their diameters are three feet, to avoid the spring of the metal. Mr. Reichenbach in Munich refuses to make any instruments of greater diameter, in consequence of the bend or spring to which they are subject.

The English prefer such constructions as admit of turning. They avoid the manual labour of filing, and therefore compose all the instruments of large diameters of pieces that can be turned. By this means, the instruments are constructed lighter and at less expense than by the former mode. Mr.

Troughton makes use of the spring of the metal itself for the adjustment of his instruments, as has been seen.

The comparison might be made to a greater extent, but such would not be consistent with the object of the present papers. It will be proper, however, in any given case to pay attention to the nature of the establishment, and the particular branches in which each artist is most distinguished, that a preference may be given to such as will be likely to give most satisfaction.

Similar considerations apply to the different kinds of time-pieces. Chronometers are of such importance to the navy, that every attention has been directed to their improvement, since their invention by Mr. Harrison. On the contrary, the improvements in clock making have been comparatively limited, and the artists employed in this branch are not so able as those employed in the construction of chronometers.

Astronomical clocks are not kept for sale as chronometers are. There are but a few constructed, and those agreeably to order only.

As to chronometers, it is hardly to be expected, that among the great numbers kept on hand by different artists, there should not be some of them preferable to others. If therefore several chronometers be required, as was my case, it will be proper to take them from different artists, in order to have a greater chance of success, which no artist can invariably attach to his work.

It must be observed, from the principles upon which chronometers are constructed, that they will go differently at sea from what they do on land. This I have proved by seven chronometers which I kept going on my passage from London to Philadelphia, and which I compared together daily. It is evident that the constant motion of the ship must affect the heavy balance, which is never affected when the chronometer is completely at rest. The quantity of this effect is of course both uncertain, and peculiar to each chronometer, both in respect to quantity and direction.

The delicacy of the scapement may be the cause why English chronometers are very liable to momentaneous gains or losses, which amount to a considerable number of seconds, though in other respects they may be very good, and may again return to their usual rate. It is probable that these may be owing to some very slight motion which occurs just at the moment when the scapement passes the stopping spring, which then may either let the wheelwork, and of course the hands, pass a number of seconds, or stop it for some time, before it recovers its free and regular play, and rate of going. This cannot be prevented in any voyage or journey.

On the continent of Europe, a much smaller number of chronometers is made, for the same reasons as stated in respect to mathematical instruments. Only the most eminent watchmakers engage in them, and they are, generally speaking, as successful as the English. The principles upon which they work are also different: but this is not the place to enter into details on this subject. It is only proper to mention that in case repairs, or even cleaning, should be necessary in a chronometer, it can seldom be expected, that any other chronometer maker will be able to do it so well as he who has made the instrument, on account of his peculiar mode of working. A like remark will apply with greater force to English and French chronometer makers.

I should advise the use of no chronometers but such as go only one day. All that go for a longer period have by no means the same degree of accuracy. It is probable that one of the causes of this arises from the too great influence of the inequalities of the springs, which must of course extend over a longer space of time.

As it is well known that the principal difficulty in the division of mathematical instruments consists now in the proper centring of the division with the axis of motion, it may be proper to mention the manner in which this is effected, and to give an idea of a dividing engine by which this error may be avoided, and which I communicated to Mr. Troughton. He approved of it so fully, that he advised Mr. Tho-

mas Jones, who made several of the instruments here described, to make his dividing engine upon the principles which I indicated.

When the instrument comes from the hands of the first workman, it is technically said to be *tight*, or fitted so as to admit little or no motion of its axis. Then the circle intended to be divided, with its axis screwed to it, is put in a lathe to receive the last adjusting turning, both with respect to the axis and the plane of the circle. For this purpose, it must turn upon two points making part of the protracted axis. As it would not turn sufficiently concentric in any common lathe arrangement with chucks, a temporary pulley is fixed to some convenient part, for the cords of the wheel to run in.

The motion should be slow and steady, to avoid all vacillation and swinging. Therefore the wheel is small, commonly one of those used with the hand lathe, and it is turned regularly by a separate person by hand.

When the axis and the plane of the circle are thus finally turned true, and before any thing is changed in the arrangements, those circles, between which the divisions are to be drawn, are immediately turned upon the plane of the instrument, by the pressure of a fine point held in a position inclined to its motion, at about an angle of ten degrees, so that no actual cutting takes place. These circles are perfectly concentric with the axis, and are described better on a silver arch than one of brass, on account of its more uniform texture and the ease with which it receives such an impression.

The instrument being now taken from the lathe, the socket of the axis, finished in the same manner, is rubbed upon it with emery and oil, by a kind of screwing motion, until an easy and even motion is obtained. This turning following always the conical surfaces by close contact, has no sensible tendency to change the centre.

The present construction of the English dividing engines requires an operation which makes the centre of the division depend on the motion of the axis. It is necessary to take

the axis out of the circle, to adapt this latter to the engine, and consequently it is not absolutely certain that the axis be screwed again exactly in its position, &c.

The dividing engines have all a centre pin, to which the instrument is centred. These pins are either fixed, or changeable, for different diameters of axes, suited to the usual and common instruments. To adapt any instrument having a central aperture for an axis different from these, a collar is turned, having its outer diameter to fit this aperture, and its central hole the centre pin of the engine. But it is evident, that the concentricity of these two circles is not always certain, and that in the last turning above mentioned, the centre may have been displaced from the centre of the aperture, which receives the axis, and which was of course not turned with it.

The division being completed, the axis is again screwed in its place, and the adjustment of it is to be made, both with respect to its concentricity and its perpendicularity to the circle. The reading of opposite verniers or microscopes must indicate the corrections which are necessary. To give the axis its proper position, it is necessary to raise three burrs with a punching tool at such places as appear to require it. By repeated trials of this kind, the axis is again centred, and this operation is to be discontinued when a sufficient approximation is obtained. When an instrument has to be removed to a considerable distance, these burrs may wear out by the greater pressure they sustain, and the instrument may become eccentric by it.

All this troublesome operation, and the disadvantages attending it, may easily be avoided, if instead of the pin or axis, the dividing machine had in the centre a circular hole of about five inches diameter, and of sufficient depth to admit the lower parts of the axis of any instrument, so that the instrument could be placed upon the engine, together with the axis, in the same situation as it came from the last turning and rubbing, without any dismounting whatever. To ease the approximate placing of the circle on the engine, a num-

ber of concentric circles of proper diameters could be drawn upon the plate.

The axis of the engines being generally very strong, would easily admit the necessary aperture in the centre; and it might for that purpose have an outer diameter of seven inches, without impeding its easy motion in the manner in which the engine is otherwise made and used. All other parts of the engine would be exactly similar to that of Mr. Troughton, as described in the Encyclopedia of Brewster; Art. *Graduation.*

The circle intended for dividing being laid upon the engine, with its axis fast to it, and centred approximately by any one of the circles, a compound micrometer microscope is placed between the two bars, at the place of the cutting tool, having its wires so placed as to form one or more tangents to the circle drawn on the instrument for the limits of the divisions. The instrument will evidently be centred, when the wire of the microscope touches this circle always in the revolution of the engine upon its axis. As long therefore as this does not take place, the position is to be corrected, half by moving the instrument properly upon the engine, and half by bringing the microscope, or its wires, nearer to, or farther from the centre; and the different circles upon the instrument may serve to verify each other.

When the instrument is thus adjusted upon the engine, it may be fastened by various means. If melted wax be cast about the parts by which the instrument is supported, it will be sufficient to keep it steady during the time required for dividing, and will not derange it by any unequal pressure.

In the present improved state of the dividing engine of Mr. Troughton, accidental errors of the divisions are scarcely possible, if due attention be paid to the proper stability of all the moveable parts, and the regularity of treading, so that no tooth of the racking wheel may be passed over, and that the tracer may not admit any vacillation in its adjustments.

The tracer of Mr. Troughton is better than the round point commonly used. It is ground below to an elliptic section, of

which the longer diameter is in the direction of the lines, and the shorter perpendicular to the same. The intersection of these two lines forms below a short and sharp edge which cuts with such ease and keenness, that on silver the tool cannot even be left to press with its full weight, and on brass its weight alone is sufficient to make a deep and sharply defined line in one stroke.

The verniers may be easily divided, by placing them on the instrument itself at such a proportional distance within the circumference of the circle as the part shall be into which they are to divide a subdivision of the instrument, and then dividing as usual. This produces evidently, when they are removed to the circumference, the loss of one division upon their full length, in their comparison with the divisions of the circle. On the dividing engine, with a tangent screw, this division can be made by the mere adjustment of its revolutions.

On some of my instruments, the pin holes which served for this operation, and which are usually filled up again, are left open, that a vernier may be restored again from the division of the instrument itself, if need should be.

It may not be improper here to mention some of the details which are to be observed in the choice of instruments, or in the direction of their construction; as their influence on the practical use of the instruments is greater than might be supposed, and as they are not always attended to by every artist.

The quality of the metal of which the framing part of the instrument is made is not indifferent, as the stability of the instrument depends in some measure upon it. If brass is used, this is subject to very great variation, without being observed by a person not well acquainted with the subject. The mixtures of copper and tin, properly cannon metal, though usually called bell metal, are much more easily distinguished in quality, and therefore preferable in many instances. The use of this metal for the axes, when the sockets are brass, or for the sockets, when the axes are steel,

must be considered as indispensable. Formerly the artists in England had for this purpose a still better metal,—the *tutenague*, imported from China, but now prohibited. The greater hardness of this metal was particularly favourable for the axes of transits, &c. which, by their frequent revolution upon the same parts, without going completely round, are very apt to become partially worn, and which cannot be made of steel, on account of its rusting. All the nobs and sockets in which the tangent screws move should be of good cannon metal; for these screws, being frequently used, will soon lose their easy motion, if they turn in brass, in consequence of their close contact and equality of texture; and after this, they acquire an inefficient or lost motion, to the great annoyance of the observer. To avoid this in all cases, I think it would be easy to adapt a spiral spring of steel wire around the screw between the two nobs in which the screw works, pressing it always to the same side of the path.

In the general construction of the instrument, attention must be paid to give to the lower parts such strength and weight with respect to the upper, as may not allow of any spring. This is the great difficulty which requires the observer's particular care in the repeating circle with two telescopes, where the main weight of the instrument is supported in equilibrio upon a small axis, so that the vertical observation must in some measure be made without touching the instrument.

The verniers which present inclined planes to the divisions must touch them in order to show accurately the coincidence and avoid parallax. This renders it necessary to give some spring to the arms which bear them, and care must therefore be taken, that they do not rub the divisions, and of course do not drag. Mr. Reichenbach in Munich avoids this by dividing the verniers upon a complete circle, which presents itself inside to the divisions in the same plane. But this requires very nice work, and as the circle is light, some care to prevent its warping, which may be occasioned by a return of some hammered parts of it to their former irregular shape.

These light parts are very liable to spring back, on being exposed to a considerable variation of temperature. By this construction, Mr. Reichenbach has applied verniers in his circle of the Paris Observatory, of which the diameter is one metre, and which is the largest size he finds advisable to give to any instrument.

The English artists, on the contrary, use compound microscopes for the readings, where the diameters are above eighteen inches, and find them to be very convenient. These microscopes, and probably the readings with them, are more accurate; but they require more labour and very accurate work.

I have already observed, that for a division by points, the micrometer must have one single wire in the direction of the radius; and for a division by lines, two wires, intersecting each other and inclined equally to the radius, making angles of about fifteen degrees on each side of the division stroke, the equality of which is very easily judged with great accuracy.

The divided circle, as well as the radii, arms, or plates bearing verniers or microscopes, ought never to be attached to other parts of the instrument, except the central piece, in order to be in all cases equally free, and left to their own spring and shape. In like manner the centre piece is to be connected with the stand part alone.

The clamping and tangent screw arrangement ought always to be strong, and never to be fixed to an arm bearing a vernier or a microscope. It is very apt to affect it differently from the other verniers, as it has to act on all parts as leader, and to overcome the resistance of the central friction. On this account, it is commonly made somewhat stronger than the others. If the verniers are not attached to a full plate, it will be best to give the instrument a separate strong arm, expressly for the purpose, and to make all arms of verniers or microscopes exactly equal.

The quality and power of the telescopes on an instrument must always exceed the degree of accuracy which is obtain-

able by the other parts of the instrument, as it serves to verify these, and also gives certainty to the observer by the accuracy of the pointing. I have always found, in terrestrial as well as celestial observations, the largest power which the telescope could bear the most advantageous for use. Great light is not an essential requisite. The distinctness of the image and its size are far preferable, as in terrestrial objects they help in pointing minutely, and in celestial observation they increase the quantity of visible or apparent motion. The same considerations show, that there is no gain in a disproportionate aperture. Accuracy of the image is lost by it, as may be easily tried by diminishing the apertures of large telescopes by covers of different openings.

In the course of my geodesical operations, I was obliged only towards winter to lay aside the greatest magnifier of the two feet theodolite, of seventy-seven times, and take the next, of about fifty times. But soon after, observations at some distance became entirely impracticable, so as to give the desired degree of accuracy.

These circumstances render it proper to choose the diameters of instruments such as to allow with propriety and ease the application of some of the telescopes which are obtained in greater perfection; and in this respect it is proper to mention here some facts relating to this subject.

The telescope which is obtained the most perfect in its kind is that of three feet and a half focal length, and about three inches aperture. For instruments, the aperture of about two inches and a half is preferred. Below that size, the telescope of thirty to thirty-two inches, with the same apertures, is obtained in great perfection. These two regulate therefore the size of the largest moveable instruments. After this, the telescope of twenty-two inches, with about an inch and three-quarters aperture, which is well suited for the eighteen inch circles, is very good for its size. The smaller sizes are made in great numbers and of various qualities, where almost no distinction can be made in respect to size, except

what chance introduces. Those, however, about thirteen inches long, for some of the better geodesical instruments, and six inches long for reflecting instruments, are the most carefully attended to. Above the three feet and a half telescope, those of five feet focal length, and three to four inches aperture, are frequently obtained very good; and Mr. Tully, Optician in Islington, has been very successful in them. Those of six feet focal length are difficult to obtain in great perfection. They have the same aperture as the five feet ones; and Mr. Dollond has made some very good telescopes of this size, though of course after many trials, and the rejection of many glasses.

A good telescope of seven feet focal length and greater, with four to five inches aperture, may be considered as the result of a happy chance, and proportionally to what is expected of such telescopes, I heard only of about three or four that had acquired a well deserved fame. Of these the largest and best is the ten feet telescope, with six inches aperture, made by old Mr. Dollond for the Greenwich Observatory, to prove the possibility of making an achromatic telescope equally as good as the ten feet reflecting telescope of Dr. Herschel. In this he actually succeeded, but only in one glass out of a number made with that view. This telescope has lately been adapted by Mr. Troughton to a transit instrument for the Observatory.

The sizes intermediate between five feet and twenty-two inches are considered as generally speaking not good. For instance, the four feet focal length is not suitable for scientific purposes. They are therefore generally mounted for pocket telescopes or spy-glasses.

In the larger telescopes, the optician is not quite certain of the focal length in the formation of his object glasses. This may vary within two inches, though the glasses come out of the same forms: but such a difference is of no importance.

A high polish to the object glasses is not desirable in instruments. The glaring light which it occasions is not agree-

able in observing. A well defined image in a milkish white light will be found more agreeable. Though the artists say that they can polish an object glass as much as they choose, without detriment to the shape of the glass, and therefore accuracy of the image, I should prefer, from experience, the greater certainty of accuracy with less polish.

The object glasses frequently contain crystallisations, which injure the brightness and accuracy of the image. These crystallisations become very apparent in the following mode of trial, which I found to be the best for judging of the accuracy of the image:—When the telescope is adjusted and directed upon a fixed star, the eye part is drawn out, which will cause the microscope which the eye glasses form, to view in its focus successively other sections of the cone of light of the object glass, and in proportion as the light will be equally diffused upon the circle so seen, and as it will bear to be more drawn out, without becoming diffused, the telescope will be more perfect and more accurately adjusted. Few telescopes will stand a very scrupulous trial of this kind. Most generally the light will be much stronger towards the circumference of the circle than in the interior, and in this will almost always be found some dark spots of angular shape, presenting themselves exactly like crystals under a microscope, which show the effect of the crystals in the glass, throwing the light from its regular course. Any stray light, as the opticians call the rays which appear as if darting out of the circle, is very apparent in this trial. The best telescopes therefore are those which, directed upon a small and not twinkling star and put a little out of focus, will present a sharply defined image with a disk like a planet. The larger this image can be made, the better the telescope.

The opticians meet with great difficulty in finding good glasses: and in making large object glasses, much more glass is wasted than is used. Various other circumstances also increase the price of the larger glasses; so that a good object

glass of a long focus and large aperture has completely a fancy price :—But it would be too tedious for me to enter here into details on this subject.

It may be proper for me to mention a source of error which may affect the accuracy of the spirit levels. These may generally be supposed to be adjusted at a mean temperature, of course a mean length of the bubble. At the higher and lower temperatures in which it is often necessary to observe, the longer or shorter bubble may measure differently in the course of the level, if this is not very regular; besides that its oscillation will at all times become sluggish and more irregular.

The manner of packing the instruments is of considerable importance for the preservation of their accuracy. The boxes ought always to be of light and straight grained wood. No piece must ever be fixed in a direction diagonal to the grain, as it will be pressed out of shape by the drying of the wood. Any piece fastened separately must always be placed in the direction of the length of the fibres. In travelling, the instrument should always be placed as much as possible in the same position in which it is used, those parts only which are not fixed to it being taken off and packed separately. The centre being the part which bears the greatest weight, must be the most firmly supported. Any stay used to steady the instrument in the box must be placed against one of its solid parts. No circle nor telescope should ever be suffered to touch the box, nor have any bearing to support or steady the instrument. They must be suspended freely in the box, by the parts destined to hold them. It is even advisable, in all cases in which the weight of the instrument allows this precaution, to make the boxes as light as possible, that in case of accident, they may break, before an effectual reaction upon the instrument can take place.

The larger instruments of the collection for the survey of the coast all travel in their boxes in the position used in observation, and are supported according to the above principles; and Mr. Troughton agreed with me in preferring this

mode of packing to the usual one, which requires the instruments to be dismounted.

On the Mechanical Organisation of a Large Survey, and the Particular Application to the Survey of the Coast.

Though the mathematical theory of such works is fully treated and well known, their practical application is left completely to the practical man; and the success and accuracy depend in a great measure on the organisation, and the different details of arrangement, which such a work requires. It may therefore be useful to give here some practical principles on this subject, in order to guide the operator in taking proper advantage of the time and circumstances, and to overcome the difficulties which are always to be met with in practical works.

The application of these to the survey of the coast may serve as an example, which at the same time will give such information with respect to that part of the work which I have executed, as may enable the operator to take advantage of it, or to continue it in future.

The leading features of the general organisation are exposed in the plans of operation which I presented to government; and now inserted in these papers; and of which the present will show the more detailed application.

The first operation is of course to find a proper place for a line of sufficient length to form the base of the triangulation, in such a situation as will enable the surveyor to arrive by simple operations and with accuracy to the determination of a distance between two elevated points, in a favourable position relative to the surrounding mountains and the country at large. If these points be at the same time the highest and freest in the neighbourhood, the multiplication of the

chances of forming the subsequent triangles will not only accelerate the work by the greater number of points which may be determined from them, but also enable the operator to choose the most advantageous combination of triangles; and if the survey shall extend over a whole country, it is proper to begin in such part of it as will soon lead to the largest triangles possible.

This was the principle which induced me to begin in the neighbourhood of New York, after I had received a letter from Mr. Dallas, Secretary of the Treasury, authorising me to begin wherever I should think it most advantageous.

The configuration of the country, particularly the direction of some principal chains of mountains, may guide us in the research for a base line, because it is generally parallel with straight ranges of mountains, that the more level and extensive plains are found, and the first triangle point will fall upon some elevation in an opposite range of mountains, if these be not very elevated.

It is therefore necessary to make first a preliminary reconnoitring survey of such a tract of the country at least as may be likely to furnish the base, and a complete system of triangles, admitting of verification. The more minutely this can be done, the more advantageous on every account will it prove for the actual survey.

In an uniform simple triangulation, it is most proper to place the two base lines, which are necessary at least in all such works, near the two extremities of the triangulation, and therefore to make also at the beginning the necessary reconnoitring for that purpose. But in my case in this work, it was desirable to obtain in an early stage of the work a verification of the linear unit upon which the triangle was founded, to allow me to make use of it for the detail surveys as soon as possible. Besides, in all cases where the triangulation is to serve for geographical purposes, it may most generally be expected that several base lines will be measured in the course of the work.

This first reconnoitring requiring the most extensive and

free view of the country, must be made early in the spring or late in the fall; for the naked woods will admit many views hidden in the summer by the branches and leaves, which may be afterwards cleared away for the work of the actual triangulation. Such was for instance my case with the base line itself and several important triangle points.

This geometrical view of a country is by no means without difficulties, and requires great attention and a kind of geometric eye, as the accuracy of the work depends much on the favourable system of triangles which is projected on these data.

The most favourable season for the actual triangulation is during spring and summer, when the length of the mornings and evenings will afford the longest time of favourable illumination for observing, which at the noon elevation of the sun is inadmissible. In this climate this time is often interrupted by the frequent rains in August.

In the fall, the atmosphere of low countries, particularly the sea shore, becomes very untransparent, and the time of the day favourable for accurate observations so limited, that it can hardly ever be expected to take a full series of angles consecutively. For instance, from my station at the east end of the verification base near Gravesend, in December, 1817, the large lighthouse off Sandy Hook, only about nine miles distant, was never visible a whole hour in the morning or evening; and as soon as the ground was warm in the morning the signal at the west end of the verification base, near five miles off, moved about irregularly in a circle of about one minute.

The winter will be fully employed in the final calculations, projecting the triangles upon paper, and other labours relative to the last summer's operations and preparatory to those for the next summer. This will occupy more persons than the actual observations have occupied in summer; as it is proper that all actual calculations be made at least double, and by different persons. The verification, comparison, and combination of the results will take up much time.

In choosing a station and in reconnoitring, due attention must be paid to select the most advantageous point of the mountain or place for the view of all the signals required, and the most conspicuous and easily discovered from other places. We must clear, in case of need, the neighbourhood so as to make the signal distinctly visible. Besides this, the ground upon which the instrument is to stand must be very solid. Unless upon rocks, or very dry hills, the solidity will hardly ever be found such as not to affect the level of the instrument by walking near it, or by the different position in which the observer stands with respect to it.

In a simple triangulation, where only few angles are observed upon the same point, it may be allowed without much inconvenience to place the instrument at any point near the actual signal which may be favourable for the observations, and to reduce the angles to the signal or station point by the angle of position and distance required. Thus we may use steeples, parts of buildings, or such fixed points, (but never trees) as station points. This however must be avoided, when a great number of angles rest upon a point, and it is to serve for detail surveys; because the consequent calculation of the reductions is actually more tedious than the calculations themselves, and because it would be very inconvenient to keep account of two such near points on the papers intended for the detail surveys.

It must however be observed, that in general steeples and buildings are always to be avoided if possible, on account of their not giving accurate signals. They should therefore only be used for the determination of their own position, and not to form points in a series of triangles.

In any case of such a reduction occurring, I used to calculate separately all the angles subtended by the eccentric distance, at each of the signals upon which angles were observed, and to combine them according to the case of each of the angles which I had to correct, as the following equation takes place in all cases :—

In Plate V. fig. 12, let

S=Station point observed.

C=Centre of the station or signal.

A & B=The two signals observed from S

Then is evidently,

$$C+A+B=180°=S+(A\pm SAC)+(B\pm SBC)$$

where the signs are easily known from angles BSC and ASC compared with ASB.

I found this method the simplest, shortest, and least liable to mistakes.

When the ground at the station point is not perfectly solid, it is necessary to place in the ground strong plugs or short posts, sawed off horizontally, and nearly level with each other.

The sand hills on the low sea shores, and the looming which takes place upon them, would have rendered necessary for these places the construction of a stand of about twenty-four feet elevation, solid and firmly attached to the ground, upon which the instrument with its stand might be placed. I intended to have had one constructed in the form of a triangular pyramid; but it is evident that the use of such means is to be limited as much as possible, on account of the many inconveniences attending them.

The instruments must be well sheltered from all weather, and the sun must not shine even upon the stand or the ground near its legs. It is therefore necessary to have a separate and suitable tent constructed for each instrument, with curtains all around, but separate, so as open the side necessary for observing, without depriving the instrument of its shelter.

The instruments are to be taken out of their boxes, placed, levelled, and adjusted in all respects, as soon as possible after arriving at the station; in order that they may recover from any unequal pressure to which they may have been subject in the boxes and in travelling, so that the parts may come to rest in their proper position some time before the instrument is used.

The chief observer, as well as all the assistants and the labouring men, must be encamped at the station, the latter not so close, as to occasion any impediment or interruption to the observations by the noise of any other necessary occupation. The living in neighbouring houses is completely incompatible with the advancement of the work.

The safest, and at the same time most expeditious and least expensive, mode of transporting the instruments is in a spring carriage constructed purposely, the body of which will closely fit the whole of the boxes of the instruments, so that they stand in it packed, without being permitted to shake.

On the first station of such a work, the task of the observer is of considerable extent, besides the mere observation of the stations. He must begin by supposing his instruments completely out of adjustment, which will certainly be the case with all moveable instruments, particularly if they have undergone any long transportation of any kind. He must adjust them, and observe with them some time, not with the view of the actual use of the observations in the work, but in order to get acquainted with his instruments, to find an easy mode of using them, and to discover all their qualities and defects.

Absolute mathematical accuracy exists only in the mind of man. All practical applications are mere approximations, more or less successful. And when all has been done that science and art can unite in practice, the supposition of some defects in the instruments will always be prudent. It becomes therefore the duty of an observer to combine and invent, upon theoretical principles, methods of systematical observations, by which the influence of any error of his instruments may be neutralised, either by direct means, or more generally and much more easily by compensation. He must not leave his first station, before he is so far clear upon this subject, as to need nothing more than the proof, always anxiously looked for, of the sum of the three angles of his first triangles. It is not here the place to present a theory on this subject, nor to enter into practical details. I will merely re-

fer to my operations with the two feet theodolite as an example.

The methods thus decided upon will determine the number, as well as the form and combination, of the observations which are required to give the greatest probability in the results, and these methods must be the constant rule for all the observations.

If observations, which are limited by their nature to a certain time, are made with repeating instruments, the number of observations must be determined by a proper combination of the theoretical formula or principle used in the case, the number of observations required to compensate the possible errors of the instrument, and the accuracy aimed at in the observation. This is the case, for instance, in circummeridian observations, &c.

The quantity of work which is made in one summer's campaign, the multiplicity and variety of cases occurring, obliterating naturally the accurate remembrance of the peculiar circumstances of an observation, which however determine the degree of relative confidence which it deserves, it is necessary to be very accurate and minute in the notation of every thing in the day books and journals kept of all observations and other operations. A certain systematic and constant form must be observed in them; they must be written with such regularity and perspicuity, that any man, with the proper theoretical knowledge, could execute the calculations, though he might have been unconnected with the work itself.

It is best to keep them in folio form, to bring as much as possible under view at once, in order to facilitate the taking out of the results for use in calculation, to admit room for all accessory notices, and bring every thing readily under the eye.

If assistance enough could be had, it would be proper always to make two fair copies from the first journal, kept under the direction of the observer. These first journals should

rather be written in ink than in pencil, for greater distinctness and better preservation, as it is proper to preserve them at least till after all calculations are made, in order to be able to verify the fair copies by them, in case of any doubt.

The method which I adopted in this respect is evident by the exemplar given of it in these papers. I distinguished the day book and journal evidently only to facilitate the order of the work by separate denominations. Every page is divided into six columns, which suit very well for all kinds of observations and results, and the headings of which go uniformly through the whole book. Not having my journals of the actual work of the coast survey at my disposition, the exemplars are taken from the similar operations made for the determination of the boundary line between this country and Canada.

The day book is kept by minute order of time. The reverse page of each leaf is destined for all the details of the observations, and the direct page facing it for the immediate results of them in all their details. The further particulars may be seen in the exemplars themselves.

The journals of results are two fold. One series of them is destined for the vertical angles, with the heading, "Of the repeating circle," though it contained vertical angles in general. The other series contained the results of all horizontal angles, and was superscribed, "Of the great theodolite," this being the instrument used. In these journals, the order of the subject is the leading principle, and they subdivide naturally, as seen in the exemplars at A and B. The date in the first columns refers each result to its observation in the day book. The next columns contain the resulting lines and angles, *&c.* forming the element of the calculation, of which all the particulars are introduced in separate columns, for the ease of the verifications. The final result with the minute details may be seen in the exemplars. I have not the opportunity of giving an exemplar for the elevation of the terrestrial objects, signals, *&c.* over the sea,

which was of course apart from the operation. But it may easily be imagined how such a journal should be kept.

The ultimate results of the work are to be collected with great order into a separate book. The mode of doing this I cannot exemplify further than will appear from No. 3 of the Journal Exemplars. The titles of the other columns depend in some measure on the formula of calculation used, the methods of projecting, and the like, besides the general results, which will always remain. Examples of it may be seen in the different accounts of measurements of degrees, &c.

For the assistants in the calculation, it was my intention, if the work had proceeded to a greater extent, to have had formulæ of blank calculations printed purposely, which is a great means of security against omissions in the calculations.

To proceed in such a work with the greatest advantage and celerity, it is proper that various assistants and an adequate number of labouring men be with the chief operator. The necessary discipline and regularity which the nature of the work requires, would, when possible, give for both the preference to military men. Good old soldiers will always be the best for the labours. The whole work must go on with the greatest regularity, to give proper confidence in the precision of it, and the desired accuracy in the results.

The better the assistants are informed in mathematics, and the more they take a proper care and active interest in the work, the more advantageous will it be. They must be furnished with written instructions upon their respective duties, and it will be proper that they change duty in regular rotation, either weekly or by station. The separate journals which they will have to keep are to be signed by them at the end of every day, to facilitate a reference to their recollection, in case of mistake.

I found the following distribution of their work advantageous:—

One to act as secretary to the observer. He is to write the names, readings on the instruments, &c. under his dictation,

and always to repeat them aloud when he has written them, to prevent mistakes; and if he is attentive, and acquainted by practice with the proper succession of the readings, he can, in case of mistaken or improbable readings, by warning the observer, cause the correction of any mistake, by a repetition of the reading before the instrument is moved. In observations requiring the notation of the time, he will count with the chronometer, and mark the moment when the word is given to him by the observer.

A second will act as an assistant observer in such observations as require it, observe regularly, at stated hours, and at the time of every observation requiring it, the barometer and thermometer, of which he will keep a regular journal, make the observations of the magnetic needle, in cases where it is of interest, as in the survey of a sea coast.

A third assistant will find sufficient employment in preliminary calculations, the making of a second copy of the day book, occasional attention to the signals, directing the men in clearing views, and various similar occupations.

One of the assistants should be a draughtsman for views, who should draw on each station the view of the whole horizon, marking the positions of all the signals, so as to indicate their place if they should be needed at any future time. The foreground of his drawing will also aid in finding the station point itself. He will also make detailed drawings of the signals, as they present themselves in the magnified scale through the largest telescope, with all the other objects accompanying it in the field of the telescope. This will direct the observer in distinguishing the signals in the smaller telescopes of the instruments from other objects which it might be easy to mistake for them.

These drawings, which will form a pretty large collection, may assist in the proper shading of the elevations in the drawing of the maps; and they may serve, if circumstances should make it desirable, to made a model in relief of a part of the country, for which many of the mathematical data are given in the survey, as the elevation of all the signals over

the sea will be determined by the vertical angles observed at the stations.

These additions to the mere horizontal survey will add more interest and usefulness to the work than might be expected, not only in a scientific point of view, but also for public utility. Joined to an accurate and minute detail survey, executed upon the principles which will be exposed hereafter, all the data should be collected, to enable the government to judge with propriety of the plan of any public undertaking or service, such as roads, canals, means of defence of the country, &c. That the survey of the coast was to contain all these data, besides the mere outlines of the coast, and that they were as necessary as the soundings outside of the line of the coast, appeared to me too evident to admit of any doubt, and I would have considered the full aim of the work missed without them.

Another addition, particularly useful to navigation, was to obtain a complete series of observations of the variation of the magnetic needle over the whole extent of the coast.

I intended that the magnetic bearings should be observed at all the stations every day by an assistant, the needle being stationary in one point for that purpose; but during the short time that I worked, the multiplicity of my other occupations and other circumstances hindered me from doing more than just to observe it once myself at the close of each station.

An oscillation needle, which I have, and which has been observed in Paris, in London, and in Washington, was intended to be observed also regularly at each station. The union of these two kinds of observation would have given an interesting result relative to this subject.

It will not be necessary to enter into the reasons which dictated the establishment of one or more observatories connected with the chain of triangles, thereby to bind the work to one or more permanent points astronomically determined. The advantage of such an arrangement is perfectly evident.

The following is the most proper order of the operations on a favourable day, at any station. Every day's work must

be brought to approach as near to it as possible. It will show that no idleness is admitted, as the omission or loss of the points here mentioned would occasion an encroachment upon the next day, or perhaps its recovering be long impeded by circumstances. I suppose the observer to be furnished with at least one instrument for vertical angles, and one for horizontal angles, time pieces, a barometer, thermometer, sextant, and artificial horizon.

The observer must be at his instruments one hour before sunrise, to test their solid standing, clean them with a feather from sandy dust, which is so often introduced by the wind into the open axes, and upon the limbs, &c. If they need any oil in the open axes, merely passing over the finger is sufficient. He must level the instruments and verify all adjustments; adjust the collimation line and the focus of the telescopes and the reading microscopes, to clear vision, and complete freedom from parallaxes, and verify the value of their reading. For all this, the quiet state of the atmosphere, and the coolness of the morning, with the full light which precedes the rising of the sun, furnish the most favourable circumstances. His instrument must necessarily be in good order, and need very little of all these adjustments, &c. if he shall be ready about sunrise, as he should; and this will be the case, if he has devoted the proper attentions at the beginning of the station.

Then he will level his instrument finally, and the rising of the sun will the proper moment to observe the angles upon the signals, within about 40° on each side of the southern meridian, until such time as the sun is about its double diameter above the horizon in case of a southern declination, or on the six o'clock meridian when in a northern declination; at which time it is proper to take one or two azimuths of the sun, in the manner indicated at the proper place.

These azimuths must be followed immediately by observations of zenith distances or altitudes of the sun, for the determination of the time, which it is necessary to have as free from the rate of the chronometer as possible, and which

should therefore be made during the azimuth observation itself, if assistants for that purpose are at hand.

After these observations, the instrument having been verified again, the observations of terrestrial angles will be continued, upon the signals from the fore mentioned situation to about due north until near ten o'clock, if the illumination of the day is favourable. About ten o'clock, corresponding altitudes may be taken with the sun, for which the easiest, and probably most accurate method will be, to take with a reflecting instrument the contact of both limbs of the sun, noting the time, and laying the instrument undisturbed and carefully aside, to observe the same again after noon. This will avoid every influence of any error of the instrument.

During the middle of the day, the state of the atmosphere and the illumination are so unfavourable to the observation of terrestrial angles, that none must be observed, the objects being all seen in the shade, and the reflection from the signals and any object in general passing high over the observer. In a hot summer day, the illumination will even cease to be favourable after 9 o'clock. But when the sun has a low southern declination, it may sometimes be possible to observe somewhat longer upon signals nearly north.

This is therefore the time to transcribe the observations into the day book, to take out the results of the terrestrial angles, to examine them, make such preliminary calculations as may be required to determine the time and rate of the chronometer, and arrange the work of the afternoon, &c.

About thirty minutes before noon, it will be necessary to adjust the vertical circle, and prepare for the circummeridian observations of the sun. For though it is not absolutely necessary in a triangulation, to determine the latitude of every station by actual observation, still it is not proper to let the sun pass the meridian without observing it, as every observation is an addition to the mass of this kind of observations, which it is necessary to have as large as possible, and they are all reduced to one point by the geodesical calculations,

within such limits as will not admit too great an influence of the figure of the earth upon the reduction.

After this observation, time may be allowed for dining, attention being paid however not to miss the corresponding altitudes of the afternoon, the time of which must be calculated approximately before hand.

Between three and four o'clock the favourable time for the observation of terrestrial angles may begin again, sometimes a little later, seldom earlier. There will be little time to lose, after the corresponding altitudes and the calculation of their result, before it will be necessary to commence the levelling of the theodolite, and the revision of all its adjustments.

The illumination will now become favourable for the signals in succession from due north past the east to about south or somewhat farther, according to the declination of the sun, as this forms the element of the angle of reflection from the signals to the observer. By this it is also evident that the time for accurate observations upon terrestrial objects becomes always more limited on both sides of noon, as the declination of the sun becomes lower, and an attention to this subject will have a great influence on the accuracy of the results.

The order of the observations in terrestrial angles, azimuths, &c. in the afternoon will be exactly the reverse of that of the morning, except that though it was possible to observe with and read on the instrument in the morning before sunrise, this will not be possible after the sun is set.

The task of the day is still not over. For it is necessary to introduce all the observations of the day book, to take out all the results and introduce them into their proper place in the journal of results, or at least into a register of the results of the station, to examine and compare them, in order to see what degree of accuracy has been obtained hitherto, and what is yet needed to complete the work of the station, and to plan accordingly for future observations. It is necessary to

do all this before any derangement of the instrument has taken place, that any discrepancy in the results may be tested and corrected immediately.

This will most likely not allow an early rest to the observer. Therefore it will hardly ever be possible to do what would now be advantageous, viz. to observe circummeridian zenith distances of stars in the night, particularly to the north, to compensate the influence of the instrument upon the observations taken to the south with the sun, and correct the result by their means. The observer will be obliged to reserve his strength for the work of the next day, as his observations would lose much of their accuracy, if he should be overfatigued. Such night observations are therefore only possible, when he has assistants able to take a part of the task of the day from him.

Night observations require besides a temporary observatory, built for the purpose, and appropriated to the instrument used, like one which I had constructed for the work of the bouudary line with Canada.

It is proper therefore that a peculiar and suitable station be selected, to make a regular and well combined series of observations on the latitudes, with all the necessary means and arrangements for accuracy. As it will then be possible to obtain many more observations of stars than of the sun, their number and kind may be so combined, as to serve as a full compensation for all the observations of the sun made at the other stations, and which are to be reduced to this by calculation.

It will naturally occur, that at such a station a complete series of azimuths may also be observed by a variety of methods, and with every means of accuracy; and that after such a station has been made, it will not be necessary to observe them on the neighbouring stations.

The indispensable observations of longitude are of course to be referred to the permanent observatory of the country, if such a one exists; if not, they also become necessary at

such stations more particularly as are made for the series of the observations of latitude ; without however excluding the observations of occultations or eclipses, which may occur on any station, and which it would never be proper to omit.

Those observations only deserve complete reliance, in any kind and case whatever, which are made under proper arrangements, and with ease to the observer. A strong glare of light which dazzles the eye, and an inconvenient position of the body must always prevent the accurate pointing of the instrument and reading of the arcs. The ease and convenience of the observer are therefore not luxuries, but are necessary to the accuracy of the observations.

Though a detailed account of the work of the survey of the coast executed during the year 1817, in which I worked at it, would not be of any general interest, and could not in fact be given, as my papers have been delivered to the government, yet I will present here, by way of record, a sketch of the principal triangles executed either fully or partially, and add a few notices, which may give an idea of the arrangement and plan of the work, and of the accuracy obtained.

It is evident, that of the accuracy which I aimed at nothing could be abated, if the work were to be such as ought to be expected in the present improved state of science. The chance of an accumulation of errors upon such a long extent of sea-coast as that of the United States, particularly in the direction in which it lies, would have been too great, the consequences of a want of system and care would have become too glaring, not to bring discredit and shame upon a less accurate operation.

The different parts of the work would have given occasion to make a number of determinations of the length of degrees of longitude and latitude. From its extent and position, it would have had particular interest, and might have served as the foundation of a system of weights and measures for this country.

The principal base line was of somewhat more than nine

thousand metres, and between *Ch* and *Vr*, Plate IX. The first triangles lie upon the points W and *Cr*. In the first, all three angles were measured, and W formed of course the main point. In the second, the angle at *Ch* could not be measured, on account of a near wood which hid the whole mountain upon which *Cr* was; while a high signal in *Ch* was distinctly observable from *Cr*. From the next point, BN, all the foregoing were observable, and vice versa. This gave occasion to bring, upon the line F and BN, the results of both into comparison, where from three triangles, of which all three angles were measured, and three in which two had only two angles measured, the two results were,—through W=15508,88 metres, and through *Cr*=15508,86 metres.

In the triangles, the sum of three angles, which I am unable to state from recollection, was satisfactory. I had not yet all the angles measured in the complete systematical order which I explained in treating of the two feet theodolite; because the great delays of all kinds which I experienced on the first station, on which I combined the method first, had occasioned me to leave it and be satisfied for the time with the number of angles I had in general.

The triangulation being now continued through S*p*, TN, LS, WE, and EE, of which the stations TN and LS could not be observed for want of time, the verification base between WE and EE was measured, and compared with the result brought from the first base by nine triangles, and the coincidence proved as follows, from all the points named:—

The distance from WE to EE was=		7752,81 met.
Without using the triangle	EE, LS, WE=	83
	EE, TN, WE=	96
By actual measurement,=		7753,

This last number in the measurement was made a round number, on account of a chain measurement made preliminarily only, though twice, and within less than half a metre in the results, being all the accuracy that can be expected by this method.

The base between C*h* and V*r* had also been measured twice with the chain carefully, and if I recollect right, there was hardly three-tenths of a metre difference in the results. As this base was intended for a standing one for the work in general, the neighbourhood of it was surveyed in detail previously, in order to lay it out in the most advantageous position for the future accurate measurement, with the apparatus described in its place.

The base between WE and EE being intended, as has been stated above, only for an early verification of the linear unit of the work, in order to be enabled to begin the detail surveys as soon as possible, would most likely not have been remeasured, but another one, at a greater distance from the first, substituted for it, in the continuation of the triangulation.

The chain with which they were measured was made purposely, of links of a metre in length, which, as they do not bend into all the small inequalities of the ground, are far preferable to small links.

The coincidence of the two bases was, under these circumstances, of course above expectation, and as it gave such a proof of the accuracy of what had been done, has brought it far within the limits of what it would in any suitable scale be possible to show upon paper, it was of course considered sufficient to serve to ground the detail surveys of the neighbourhood on the triangles executed from these, which are seen in the sketch.

The point H was intended for the continuance of the survey to the east connected with W: the points S*p* and B were intended for the same purpose towards the south.

The distance HF having been determined both through W and through C*r*, had given a coincidence sufficiently satisfactory for the few angles which it had been possible to measure upon H from C*r* and W, which would of course have been repeated in the further operations, and corrected by the observations on H itself.

Through W the result was=42392,03 metres.

Through *Cr* the result was=42391,64

The other coincidences being equal to these, in general it appeared to me evident, that in applying the method described when treating of the two feet theodolite, in the angles of the main triangles, I could reach the accuracy of less than one second in the sum of the three angles, with full certainty always, and that only one pair of direct and reversed observations was fully sufficient to determine any near detail point; that it was therefore most advantageous to observe them in this manner from any station where they would be visible, as this gave a verification from different bases.

The azimuths observed gave results equally satisfactory, so far as they were calculated, but as their calculation was not completed, when the work was interrupted, what had been done was again cast away, as it did not present a final result, and might, by being considered as such, rather mislead than serve for any useful purpose. This was so much the more proper, as they were all to be considered as merely preliminary.

I had built in Newark, in my garden, a small observatory which could be determined from BN, and in which I intended to make a regular series of latitude, longitude, and azimuth observations, as stated above.

It will easily be observed, in the sketch of the triangles, which are the stations on which I observed any angle, the lines of the triangles being there drawn full, while to the points on which I had not observed, they are merely dotted.

The angles of elevation of the principal points were taken on all stations, so that their relative height can be calculated. To reduce it to the level of the sea, I levelled actually from the point N down to the water, this point being close to the shore, in the narrows, upon the high eastern bank.

The results of all that relates to this have not been calculated, as this could only take place after the calculation of the distances. The geodesical parts were of more importance to obtain first, as they lay nearer to immediate use.

Latitudes were observed on various stations, for temporary use in the determination of time, &c. The longitude was taken from the general acceptation of the longitude of New York ; but all this to determine accurately, was of course referred to regular observations in the temporary observatory built for the purpose.

The organisation of the detail surveys always depends upon the administrative views according to which the work is to be executed. Its details must therefore be omitted in the present papers. Regular and full instructions must be given to the detail surveyors in writing, both on the principles which they shall make use of in their works, and on the objects to be attended to. The nature of the first is indicated to them by the instruments which they are to employ, and by the papers containing the triangulations which are given them to fill up, with the detail notices which shall accompany them. The mere elementary mathematical part is sufficiently treated of in a number of works. The latter must be reduced into regular tables forming the questions, which they shall answer by filling them up ; and in an extensive work they should be in printed formulæ. Their nature, in the survey of the coast, is evident, from what has been said before upon this subject. I intended to plan such instructions, after my summer's work was finished.

The plane table is the most appropriated practical means that can be used for actual surveying in this case. It is also the most accurate and expeditious. Every other means will be found to require more labour, and to multiply the chances of disadvantage and error.

This part of the work is much more expensive and tedious than the triangulation. The surveys must be laid down on a large scale, $\frac{1}{2000}$ at least. The ports and harbours ought to be at $\frac{1}{10000}$. And all may be brought to an assemblage with convenience and propriety in the scale of $\frac{1}{50000}$ at least.

If the governments of those States through which the survey of the coast was to go, could be induced to take an inte-

rest in this part of the work, I considered the utility of the work would be much extended, both for the general government and those States, the proportional expenditure much diminished by their distribution, and the final execution more accelerated than could be possible by any other means. In the execution of the triangulation, it was easy to suit some peculiar want or interest of any State. This would have added double value to the work for this State, without increasing the expenditures and the work by any amount worth consideration.

Some remarks upon the best methods of transferring the result of the triangulation to paper may be inserted here; as frequently much of the accuracy of the work is lost by insufficient methods, and these are left to the knowledge and practical skill and experience of the operator, though the analytical formulæ of calculation and the principles of projection have been treated repeatedly and extensively.

In former works I have always found the calculation of the points in degrees, minutes, seconds, and decimals more convenient for this use than those in linear measures; and as the approximation can be carried, by the decimals of seconds, farther than it is possible to subdivide actually upon paper, there is no accuracy lost, particularly as all the decimals are always preserved in summing up any number of results that concur in the determination of a point, just as the logarithms obtained in the calculation are always used in any place where the results are required, and not again a logarithm of the number found anew; any loss in the fractions in transferring to paper having thereby no farther influence than upon the point itself.

I made a table of the values of the minutes, seconds, and decimals of latitude and longitude for all those parts of the projection which had been calculated, for the subdivisions of the different trapezii, which were traced by the projection, and which I commonly made only of five minutes at most, both in latitude and longitude, in order to bring the distances

to be laid off from them within the limits of usual dividers; and in this manner every point was laid off by rectangular ordinates, from the nearest sides of the trapezium of the projection.

The accuracy of the projection is therefore the basis upon which the accuracy of the whole work depends, and to this great attention is to be paid. It will, on every sheet, begin by a right angle in the middle, extending over the whole paper both in latitude and longitude; and to obtain this with accuracy, as well as in all other parts of the construction, it is necessary to assist the eye with a magnifying glass, to augment the sharp vision of the small points, which it is only allowed to make, if the sinking of the beam compass shall not introduce errors in the work.

It is not allowed to use any compasses but those with rectangular points. For the smaller parts, the proportional beam compasses, No. 46 of the Catalogue of Instruments, were intended. They are very convenient in the hand, and easy to support against making too deep points. To prevent the beam compasses from making deep impressions, and to ease their guidance, I used to suspend them over the table by a roller with a counterpoise.

It is evident that in no case whatever a method of laying off a point, by means of an angle any how constructed, can be applied in these works. The only place where these are admissible is in the plane table operations, and in laying off points of soundings with the station pointer, observed by the problem of three points.

The projection which I intended to use was the development of a part of the earth's surface upon a cone, either a tangent to a certain latitude, or cutting two given parallels and two meridians, equidistant from the middle meridian, and extended on both sides of the meridian, and in latitude, only so far, as to admit no deviation from the real magnitudes, sensible in the detail surveys. I had just commenced some calculations relative to the question,—which radius of the earth was most advantageous to admit the greatest extent to

the projection under the above condition, whether the geocentric radius of the latitude, the radius of curvature of the meridian at the tangent point, or the radius of the sphere tangent to the spheroid at the point. Further than this I had not proceeded, when I abandoned the subject, by the interruption of my work.

It is at all events necessary that these projections go off from different points of latitude, and be all of equal extent from the central meridian and parallel, in order that the deviations from the real magnitude may never become so great as to require the application of correction for the plane table operations, which determine of course the details in the neighbourhood of any point of a triangle from the position of these points, as laid down by the projection,—and that in bringing the different parts together, their points on the edges may meet again completely, being equally affected by the projection.

In each of these sheets, it was intended to bring the results of several parallels, so that the central meridian alone should become a straight line, and all the other meridians and parallels broken lines, nearest the curve, to which they belong; the angular points of the trapezium being transferred to paper by their rectangular ordinates, from the middle right angle, calculated from the angle at the centre of the projection, in the protracted axis of the earth.

The papers to be given to the detail surveyors should be divided differently: viz. they must always contain those points, and extend over such parts as may, by the nature and configuration of the country, be best adapted to be surveyed together. But the points must be laid down upon them according to the place which they would occupy in the above regular distribution of the projections.

This distribution of the projection, in an assemblage of sections of surfaces of successive cones, tangents to or cutting a regular succession of parallels, and upon regularly changing central meridians, appeared to me the only one

applicable to the coast of the United States. Its direction, nearly diagonal through meridian and parallel, would not admit any other mode founded upon a single meridian and parallel, without great deviations from the actual magnitudes and shape, which would have considerable disadvantages in use.

Their union in one general map on a small scale would be exceedingly easy, and in making a minute projection, could almost be done without the aid of instruments.

EXEMPLARS

OF THE

DAY BOOK AND JOURNAL OF RESULTS.

NOTE.—In the Manuscript, the twelve columns used in each of the following pages are extended over two pages,—six being placed on each; and a reference to this arrangement is made in the body of the Paper. It was found impracticable, however, to print them in this form: but it is believed that the change will not give rise to any embarrassment.

EXEMPLARS FOR THE DAY BOOK.

1818. *Station near Chateaugay River.*

♂ 29th September, PM. Time by Chronometer, No. 50, Hardy. Obs. times. h. ′ ″	Mean of times.	Double altitude of the Sun with the Reflecting Repeating Circle for determination of time. Readings of the Mirror. A. ° ′ ″	B. ° ′ ″	Readings of the Circle. C. ° ′ ″	D. ′ ″	Results.	° ′ ″		Mean Altitudes. ° ′ ″	(By N. N.)
3 52 40,0		300 00 00	0 00 00							
3 53 52,0				47 32 25	.. 32 18	By A.	177 59 25	177 59 24 / 10 =	17 47 56,4	
3 54 17,5	h. ′ ″					B.	177 59 23			
3 54 50,0	3 55 12									
3 55 12,0										
3 55 31,0										
3 55 57,5										
3 56 15,0						C.	177 13 07	177 13 26,5 / 10 =	17 43 20,6	
3 56 33,0	3 55 40	117 59 25	0 59 23							
3 56 52,0				224 45 32	.. 46 04	D.	177 13 46			
3 57 20,5										

Barometer, 29,93. Thermometer, 66°, Fahr.

Immediately after. Names of places.			Objects.	Azimuth Angles with the Two Feet Theodolite. Readings of the Microscopes. A.	B.	C.	Results of each Microscope. A. ° ′ ″	B.	C.	Mean.	Denomination of Angles.
Upon the Hill West.			Signal.	22 32 08,0	.. 15 38,0	.. 57 26,0	Telescope Direct.				
Time by Chronometer, as above.							20 45 29,0	20 45 17,0	20 45 33,0	20 45 26,3	⊙ and West Signal.
4 07 54,0											
4 08 28,8	(4 08 28,9										
4 09 04,0		4 09 55,25	⊙	1 46 39,0	.. 30 21,0	.. 11 53,0					
Clouds.											
4 11 21,6	) 4 11 21,6										
4 11 56,7											
4 13 05,5											
4 13 39,5	(4 13 39,725										
4 14 14,4		4 15 36,96	⊙	182 48 06,0	.. 30 45,0	.. 12 34,0	Telescope Reversed.				
4 16 58,7											
4 17 34,2	) 4 17 34,2						19 46 23,0	20 45 07	20 44 43,5	19 45 21,2	⊙ and West Signal.
4 18 09,7											
Upon the Hill West.			Signal.	202 31 06,0	.. 15 52,0	.. 57 17,5					

Immediately after. Chronometer as above. ″			Double Zenith Distance ⊙ with the Repeating Circle for determination of time. D.	E.	F.	G.	Results of each Alhidade.				Mean of opposites.		Mean.
4 23 37,7													
4 24 23,3	⁀23,225												
4 25 18,6		25′ 58″,05											
4 26 47,0			90 00 00	+12″	+17″	—02″	D.	155 47 08	E.	155 46 34	155 46 40,5	155 46 44,7 / 2 =	° ′ ″ 77 53 22,3
4 27 32,6	⁀32,875												
4 28 19,3							F.	155 46 13	G.	155 47 04	155 46 49,0		
Mean of times, 4h. 29′ 24″,431													
4 30 37,8													
4 31 19,7	⁀19,2												
4 31 59,6		32′ 50″,812	245 47 08	.. 46 46	.. 46 30	.. 47 02							
4 33 36,8													
4 34 22,7	⁀22,425												
4 35 07,5													

Barometer, 29″,91. Thermometer, 62°, Fahr.

Station in the Manor.

1818.

♃ 15th October. Time by Chronometer, No. 50, Hardy.		Double Zenith Distance of ☉ at noon with the Repeating Circle. Readings of each Alhidade.				Results of each alhidade.			Mean of opposites.		Mean.
											° ′ ″
11 36 52,0 ⌣	D=	42 35 00	E .. 35 18	F .. 36 17	G .. 35 38						
11 40 01,5 ⌢	W=	96 20 07	X .. 21 17	Y .. 20 12	Z .. 23 12	D=	281 41 47	E .. 47 50	281 48 09	641 48 07,5 / 12 =	53 29 00,6
11 42 54,0 ⌣						F=	.. 47 31	G .. 48 50	 06		
11 44 23 5 ⌢											
11 46 13,5 ⌣						W=	281 47 45	X .. 48 55	281 48 30,5	641 48 55,5 / 12 =	53 29 06,3
11 47 31,0 ⌢		Barometer,	29,901			Y=	.. 49 16	Z .. 49 46	.. 49 20,5		
11 48 32,0 ⌣		Thermom.	64°								
11 49 39,0 ⌢											
11 50 37,5 ⌣											
11 51 47,0 ⌢											
11 52 46,0 ⌣											
11 53 48,5 ⌢	D=	324 23 47	.. 23 08	.. 23 48	.. 24 00						
11 54 47.0 ⌣	W=	18 08 02	.. 10 12	. 09 28	.. 12 58						
♀ 16th October, PM. Chronometer, as above		Double Zenith Distance of the Pole Star with the Repeating Circle.									
10 47 04	D=	11 17 03	.. 17 07	.. 17 33	.. 17 38						
10 52 16	W=	54 34 36	.. 36 00	.. 35 17	.. 38 42						
10 53 49											
10 56 19											
10 58 00											
10 59 00						D=	119 25 14	.. 25 08	119 24 56,5	1559 24 45,5 / 36	=43 19 01,27
11 00 42						F=	.. 24 39	.. 24 01	 34,5		
11 01 36											
11 03 00		Barometer,	30,9								
11 05 35		Thermom.	31°								
11 06 51											
11 07 51											
11 09 06											
11 10 00						W=	119 26 26	.. 25 40	119 25 39,5	1559 25 41,75 / 36	=43 19 02,5
11 11 18						Y=	.. 24 53	 48	 44,0		
11 12 18											
11 13 31											
11 15 43											
11 17 09											
11 18 12											
11 19 40											
11 21 11											
11 22 19											
11 23 43											
11 24 58											
11 26 49											
11 28 02											
11 29 29											
11 31 06											
11 32 41											
11 34 33											
11 35 57											
11 36 48											
11 38 28											
11 39 32											
11 40 42	D	130 42 17	.. 42 15	.. 42 12	.. 41 39						
11 42 11	W	174 01 02	.. 01 40	.. 00 10	.. 04 30						

Station of St. R.

1818.

☿ 1st July, AM. Chronom. No. 50, Hardy.	Readings of—	A	B	C	Azimuth Angles with the Two Feet Theodolite. A	B	C	Mean.	Denomination of the Angles.
h. ′ ″					Telescope	Direct.			
5 22 26,5 5 23 06,0 (23 06,5 5 23 57,0 5 25 41,0 5 26 21,0) 26 21,17 5 27 01,7 — 5h. 24′ 43″,76	⊙	129 33 46,4 45,0	.. 18 32,0 32,1	.. 00 24,0 23,0	24 41 08,9	 05,25	 10,5	24 41 08,22	Sun and Signal in Cut.
Cut to Fr. M.	Signal top.	154 14 54,8 54,4	.. 59 38,4 38,2	.. 41 34,0 34,0					
					Telescope	Reversed.			
5 37 40,7 5 38 21,0 (38 21,17 5 39 32,0 5 40 58,2 5 41 37,4) 41 39,25 5 42 20,0 — 5h. 40′ 00″,21	⊙	312 04 01,0 00,4	.. 48 31,0 31,8	.. 29 34,9 34,9	22 11 04,1	.. 10 43,35	.. 13 59,8	22 10 55,75	.. ..
Cut to Fr. M.	Signal top.	334 15 04,6 05,0	.. 59 14,4 15,1	.. 40 34,8 34,6					

N. B.—An Observation of time was made immediately after, and then the Terrestrial Angles continued, as follows:—(Telescope Direct.)

					A	B	C	Mean.	Denomination of the Angles.
On the Island.	Signal top.	112 08 40,0 40,0	.. 53 15,0 14,0	.. 35 05,5 06,0	28 19 47,0	 59,5	 63,25	28 19 56,6	Island and St. R. S.
East End of St. R.	Signal pole.	140 28 28,0 26,0	.. 13 13,0 15,0	.. 55 09,0 09,0	42 06 20	 25,5	 33,25	42 06 26,25	Island and Cut to Fr. M.
Cut to Fr. M.	Signal top.	154 15 00	.. 59 40	.. 41 39	40 41 53	 44,0	 43,0	41 41 46,6	St. R. and Black Cross.
Near the Black Cross.	Signal foot.	181 10 20	.. 54 58	.. 36 43					
					Telescope	Reversed.			
On the Island.	Signal top.	292 09 01	.. 53 43	.. 34 36	28 20 10,0	.. 19 52,0	.. 20 12,0	28 20 04,7	Island and St. R. S.
East End of St. R.	Signal pole.	320 29 11	.. 13 35	.. 54 48	42 06 33,0	 00,0	 31,0	42 06 20,3	Island and Cut to Fr. M.
Cut to Fr. M.	Signal top.	334 15 34	.. 59 43	.. 41 07	40 41 56,5	 19,0	 46,0	40 41 40,5	St. R. and Black Cross.
Near the Black Cross.	Signal foot.	1 11 07	.. 54 54	.. 36 34					
SAME DAY, PM.					Telescope	Reversed.			
On the Island.	Signal top.	292 08 49,0	.. 53 33,5	.. 34 23,3	28 20 03,5	.. 19 44.0	.. 20 03,7	28 19 57,4	Island and St. R. S.
East End of St. R.	Signal pole.	320 28 52,5	.. 13 17,5	.. 54 27,0	40 41 51,5	 13,5	 41,7	40 41 35,6	St. R. and Black Cross, S.
Cut to Fr M.	Signal top.	334 15 20,0	.. 59 31,0	.. 40 53,0	42 06 31,0	.. 05 57,5	.. 06 29,7	42 06 19,4	St. R. and Fr. M. S.
Near the Black Cross.	Signal foot.	1 10 44,0	.. 54 31,0	.. 36 08,7					
					Telescope	Direct.			
On the Island.	Signal top.	112 08 24,0	.. 52 53,5	.. 34 47,0	28 19 50,0	.. 20 04,5	.. 20 08,0	28 20 00.8	Island and St. R. S.
East End of St. R.	Signal pole.	140 23 14,0	.. 12 58,0	.. 54 55,0	40 41 51,0	 44,5	.. .. 42.0	40 41 46 0	St. R. and Black Cross.
Cut to Fr. M.	Signal top.	154 14 10,0	.. 59 19,5	.. 41 19,5	42 06 16,0	 26,0	 32,5	42 06 24,8	St. R. and F. M Cut.
Near the Black Cross.	Signal foot.	181 10 05,0	.. 54 42,5	.. 36 37,0					

N. B.—These signals being so near, that every part of them was distinguishable, the reduction for illumination was not needed. If they had been more distant, the sun would have been observed at intervals, or at the beginning and end of each series, by the reading of the microscope A only, to determine the angle of reduction. For the same reason also, the microscopes were not continued to be read double, or from both nearest divisions on each side, as would otherwise have been done.

☿ 8th July, PM. Chronom. No. 50, Hardy.			Azimuth Angles with the Two Feet Theodolite.—(N. B. Immediately after an Observation of Time.) A.	B	C	Telescope Direct. A.	B	C	Mean.	Denomination.	
h. ′ ″	′ ″										
5 44 57,5 5 45 39,5 5 46 21,5	45 39,5	5h. 47′ 21″,75									
5 48 22,0 5 49 04,0 5 49 46,0	49 04,0		⊙	106 05 46,0 48,8	.. 50 11,7 11,7	.. 32 09,8 09,0	168 00 29,6	 53,8	167 59 59,9	168 00 21,1	⊙ and F. M. Signal.
Cut to F. M.			Signal top.	274 06 15,5	.. 51 05,5	.. 31 49,3					
							Telescope Reversed.				
6 00 01,5 6 00 43,5 6 01 25,7	00 43,55	6h. 02′ 24″,71									
6 03 24,0 6 04 06,0 6 04 47,5	04 05,87		⊙	288 33 07,7 08,6	.. 17 52,4 52,0	.. 58 42,2 42,2	165 33 16,85	.. 32 47,8	.. 33 48,8	165 33 14,45	.. ..
Cut to F. M.			Signal top.	94 06 25,0	.. 50 40,0	.. 32 31,0					

Station on the Island.

♄ 11th July, AM.	Horizontal Angles with the Two Feet Theodolite.—(Telescope Direct.)								
Cut to F. M.	Signal top.	9 48 11,0	.. 31 52,0	.. 13 37,2					
East End St. R.	..	70 43 10,0	.. 27 15,0	.. 08 53,0	38 58 11,8	 36,0	 53,0	38 58 33,6	Main Station & E. St. R.
Main Station Point.	..	109 41 21,8	.. 25 51,0	.. 07 46,0	99 53 10,8	 59,0	.. 54 08,8	99 53 46,2	.. Cut to F. M.
					Telescope Reversed.				
Cut to F. M.	..	189 47 23,5	.. 31 55,0	.. 13 37,5	38 58 41,9	 33,0	 41,7	38 58 38,9	.. East St. R.
East End St. R.	..	250 42 45,3	.. 27 39,7	.. 08 22,5	99 54 03,7	 17,7	.. 53 28,5	99 53 56,6	.. Cut to F. M.
Main Station Point.	..	289 41 27,2	.. 26 12,7	.. 07 04,2					
The Theodolite turned one change of legs forwards.									
Main Station Point.	Signal top.	170 00 42,4	.. 45 20,3	.. 27 10,0	99 53 26,2	.. 54 00,5	.. 54 12,0	99 55 52,9	.. Cut to F. M.
East End St. R.	..	131 01 56,3	.. 46 42,0	.. 28 36,8	38 58 46,1	 38,3	 33,2	38 58 39,2	.. East St. R.
Cut to F. M.	..	70 07 16,2	.. 51 19,8	.. 32 58,0					
					Telescope Direct.				
Main Station Point.	..	350 01 04,8	.. 44 55,3	.. 26 35,0	99 54 15,4	.. 53 17,3	.. 54 13,8	99 53 55,5	.. Cut to F. M.
East End St. R.	..	311 02 14,3	.. 46 45,0	.. 27 58,0	38 58 50,5	 10,3	 37,0	38 58 32,6	.. East St. R.
Cut to F. M.	..	250 06 49,4	.. 51 38,0	.. 32 21,2					
The Theodolite turned one change of legs forwards.									
Main Station Point.	Signal top.	230 43 07,3	.. 27 53,4	.. 08 48,7	99 54 12,3	 18,4	.. 53 16,7	99 53 55,8	.. Cut to F. M.
East End St. R.	..	191 44 31,0	.. 29 06,0	.. 10 41,2	38 58 36,3	 47,4	 07,5	38 58 30,4	.. East St. R.
Cut to F. M.	..	130 48 55,0	.. 33 35,0	.. 15 32,0					
					Telescope Reversed.				
Main Station Point.	..	50 43 40,3	.. 27 30,0	.. 09 10,0	99 54 15,3	.. 53 31,5	.. 53 58,0	99 53 54,9	.. Cut to F. M.
East End St. R.	..	11 45 04,0	.. 28 41,0	.. 10 30,0	38 58 39,3	 49,0	 40,0	38 58 42,8	.. East St. R.
Cut to F. M.	..	310 49 28,0	.. 33 58,5	.. 15 12,0					

Station in Cut to F. M.

♂ 14th July, AM.	Horizontal Angles with the Two Feet Theodolite.									
					Telescope	Direct.				
On the Island.	Signal top.	103 53 31,0	.. 37 45,3	.. 19 40,0	37 59 24,0	 38,0	 56,3	37 59 39,43	On the Island	and Main Station.
East End St. R.	..	75 42 45,6	. 26 49,4	.. 08 27,3	28 10 45,4	 55,9	 72,7	28 10 58,0	..	East St. R.
Main Station Point.	..	65 54 07,0	.. 38 07,3	.. 19 43,7						
					Telescope	Reversed.				
On the Island.	..	285 53 41,0	.. 38 28,0	.. 19 20,8	37 59 46,5	 48,0	 45,4	37 59 46,63	..	Main Station.
East End St. R.	..	255 42 40,2	.. 27 28,0	.. 08 19,0	28 11 00,8	 00,0	 01,8	28 11 00,9	..	East St. R.
Main Station Point.	..	245 53 54,5	.. 38 40,0	.. 19 35,4						
	The Theodolite turned one change of legs forwards.									
On the Island.	Signal top.	163 06 33,7	. 51 01,7	. 33 01,0	37 59 48,0	 42,9	 48,0	37 59 46,3	..	Main Station.
East End St. R.	..	134 55 28,3	.. 39 58,0	.. 21 54,0	28 11 05,4	 03,7	 07,0	28 11 05,4	..	East St. R.
Main Station Point.	..	125 06 45,7	.. 41 18,8	. 33 13,0						
					Telescope	Direct.				
On the Island.	..	343 06 49,0	.. 50 59,3	.. 32 19,0	37 59 53,4	 25,3	 36,6	37 59 38,4	..	Main Station.
East End St. R.	..	314 55 42,9	.. 40 13,0	.. 21 23,3	28 11 06,1	.. 10 46,3	.. 10 55,7	28 10 56,03	..	East St. R.
Main Station Point.	..	305 06 55,6	.. 51 34,0	.. 32 42,4						
	The Theodolite turned one change of legs forwards.									
On the Island.	Signal top.	222 59 30,0	.. 44 15,0	.. 25 32,8	37 59 37,0	 54,8	 27,8	37 59 39,9	..	Main Station.
East End St. R.	..	194 48 41,0	.. 33 11,0	.. 14 51,8	28 10 49,0	 64,0	 41,0	28 10 51,3	..	East St. R.
Main Station Point.	..	184 59 53,0	.. 44 20,2	.. 26 05,0						
					Telescope	Reversed.				
On the Island.	..	43 00 17,0	.. 44 05,8	.. 25 39,3	37 59 51,5	 51,8	.. . 48,3	37 59 50,3	..	Main Station.
East End St. R.	..	14 49 15,0	.. 33 01,5	.. 14 38,0	28 11 02,0	 04,3	 01,3	28 11 02,53	..	East St. R.
Main Station Point.	..	5 00 25,5	.. 44 14,0	.. 25 51,0						

REMARKS.

Latitude Observations with the Repeating Reflecting Circle are registered, in respect to time, like those of the Repeating Circle with Two Telescopes; and in respect to the angles, like an Observation of Time with the Reflecting Circle.

Observations of zenith distances of terrestrial objects or signals being made exactly like those of celestial objects, are registered in like manner, the time excepted, which is omitted. But it is proper to read one vernier at each observation, and write it in the proper column of the Journal, in order to have a sure check upon the number of angles and the regularity of the observation.

The registering of the observations with the Repeating Theodolite is, in all respects, similar to that with the Repeating Circle for vertical angles,—and this as well for horizontal as for vertical angles; for the horizontal angles are taken in the same order as the observations of the vertical angles upon terrestrial objects. The denomination of the angle is placed at the top of the observation.

EXEMPLARS FOR THE JOURNALS OF RESULTS.

1. *Of the Repeating Circle.*

A. DETERMINATION OF TIME.

Station near Chateaugay River.

1818.	Time of Chron No. 50, Hardy	Zenith Distance of ☉ observed.	Declination South.	True Time.	Mean Time.	Difference of Chronom. with True Time.	Difference of Chronom. with Mean Time.	Mean.	Rate.		Denomination of instruments
	h. ′ ″	h. ′ ″	° ′ ″	h. ′ ″	h. ′ ″	h. ′ ″	′ ″	h. ′ ″			
29th Sept. PM.	3 55 12,0	72 12 03,6	2 25 03,6	4 06 51,46	3 57 10,01	0 11 39,46	.. 01 58,01	0 01 58,44			Reflect. Circle
	 40,0	.. 16 39,35	 14,95	.. 07 22,33	 38,88	 42,33	.. 01 58,88				Repeat Circle
	4 29 24,43	77 53 22,3	 47,64	.. 41 03,33	4 31 22,42	 38,9	.. 01 57,99				

B. DETERMINATIONS OF LATITUDES.

Station in the Manor.

1818.	Time of Chron. No. 50, Hardy.	Distance from the Transit.	Factors of Reduction. a	Factors of Reduction. b	Observ. Zen. Dist. of ☉	Reductions.	Merid. True Zen. Distance	Declination.	Latitude.	Mean of Front & Back	
15th October.	h. ′ ″	′ ″									
	11 36 52,0 ◡	8 43,1	149,23	0,055							
	11 40 01,5 ◠	5 33,6	60,69	9	Front.	Red. =—46,62					
	11 42 54,0 ◡	2 41,1	14,15		° ′ ″	Refr. } +69,39	° ′ ″		° ′ ″		
Noon. 11h. 45′ 35″,1	11 44 23,0 ◠	1 12,1	2,88		53 29 00,6	—Pa. }	53 29 23,33		45 00 47,83		
	11 46 13,5 ◡	0 38,4	0,80								
	11 47 31,0 ◠	1 55,9	7,33			S=+22,73		° ′ ″		° ′ ″	
	11 48 32,0 ◡	2 56,9	17,06					8 28 35,5		45 00 45,41	
	11 49 39,0 ◠	4 03,9	32,44	2							
	11 50 37,5 ◡	5 02,4	49,87	5							
	11 51 47,0 ◠	6 11,9	75,43	13	Back.	—47,2	″		″		
	11 52 46,0 ◡	7 10,9	101,26	25	53 29 06,3	+69.39	 28,49		 42,99		
	11 53 48,5 ◠	8 13,4	132,76	0,043							
	11 54 47,0 ◡	9 11,9	166,11	0,067		S=+22,19					
Barometer,	29,20	Front,	643,90	0,152							
Thermometer,	64°	Back,	650,78	0,164							

16th October.	10 47 04,0	29 17 8	1683,00	6,866	Polaris.					
	10 52 16	24 05,8	1139,20	3,144						
	10 53 49	22 33,8	998,80	2,418						
	10 56 19	20 02,8	788,54	1,507						
	10 58 00	18 21,8	661,76	1,062						
	10 59 11	17 10,8	579,26	0,814	Front.					
	11 00 42	15 39,8	481,54	0,563	° ′ ″					
	11 1 36	14 45,8	427,82	0,444	43 19 01,27					
	11 3 00	13 21,8	349,61	0,296		″				
	11 5 35	10 46,8	228,13	0,126		Red. −12,91				
	11 6 51	9 30,8	177,68	76		Ref. +59,02	43 19 47,38		45 00 45,74	
	11 7 51	8 30,8	142,29	51						
	11 9 06	7 15,8	103,58	25		S=+46,11				
	11 10 00	6 21,8	79,50	5						
	11 11 18	5 03,8	50,33	2						
	11 12 18	4 03,8	32,42							
	11 13 31	2 50,8	15,91							
Transit.	11 15 43	0 38,8	0,82							
11 16 21,8	11 17 09	0 47,2	1,21							° ′ ″
	11 18 12	1 50,2	6,67					+		
	11 19 40	3 18,2	21,42	1				88 20 33,12		45 00 44,82
	11 21 11	4 49,2	45,61	4						
	11 22 19	5 57,2	69,58	12						
	11 23 43	7 21,2	106,16	26						
	11 24 58	8 36,2	145,31	51						
	11 26 49	10 27,2	214,52	0,111						
	11 28 02	11 40,2	267,35	0,173						
	11 29 29	13 07,2	337,89	0,276	Back.					
	11 31 06	14 44,2	426,26	0,440	43 19 02,8					
	11 32 41	16 19,2	522,74	0,662			 49,22		 43,90	
	11 34 33	18 11,2	649,20	1,020		−12,60				
	11 35 57	19 35,2	752,81	1,372		+59,02				
	11 36 48	20 26,2	819,56	1,626						
	11 38 28	22 06,2	958,50	2,225		+46,42				
	11 39 32	23 10,2	1053,20	2,689						
	11 40 42	24 20,2	1161,90	3,271						
	11 42 11	25 49,2	1307,64	4,145						
Barometer,	30,90	Front,	15500,09	31,373						
Thermomet.	31°	Back,	15124,73	28,652						

2. *Journals of the Results of the Great Theodolite.*

A. AZIMUTH.

Station of St. R.

1818.	Time of Chron. No. 50, Hardy.	True Time.	Declination.	Denominat. of terres. objects	Stand of the Telescope.	Terrestrial Angle observ.	Azimuth calculated.	Azimuth of the Object.	Mean of Dire. and Reversed.	Mean of Fore & After Noon.	General Mean.
	h. ′ ″	h. ′ ″	° ′ ″			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
1st July, AM.	5 24 43,76	5 22 16,2	23 09 58,0	Signal in Cut.	Direct.	24 41 08,22	67 00 51,1	91 41 59.32	91 42 00,65		
	.. 40 00,21	.. 37 32,6	 56,0	..	Reversed.	22 10 55,75	69 31 06,2	.. 42 01.95		91 41 57,9	
8th July, PM.	5 47 21,75	5 43 51,5	22 29 47,0	..	Direct.	168 00 21,1	76 18 20,2	.. 42 00 8			
	6 02 24,71	. 58 54,44	 44,0	..	Reversed.	165 33 14,45	73 51 24,9	.. 41 49,55	.. 41 55,17		

B. TERRESTRIAL ANGLES.

Station of St. R.

1818.	Teles. Stand.	Observed Angle.	Mean of Direct and Reversed.
		Signals in Cut	and on Island.
		° ′ ″	″
1st July, AM.	D	42 06 26,25	 23,27
	R	 20,3	
PM.	R	 19,4	 22,1
	D	 24,8	
		Mean,	42 06 22,7

Station on the Island.

		Main Station &	Signal in Cut.
11th July, AM.	D	99 53 46,2	 51,4
	R	 56,6	
	R	 52,9	 54,2
	D	 55,5	
	D	 55,8	 55,35
	R	 54,9	
		Mean,	99 53 53,65

Station in the Cut to F. M.

		Main Station &	Island Signal.
14th July, AM.	D	37 59 39,43	 43,03
	R	 46,63	
	R	 46,3	 42,35
	D	 39,4	
	D	 39,9	 45,2
	R	 50,5	
		Mean,	37 59 43,53

Collection of the Triangles and Geographical Positions.

Number of the Triangle.	Num. of Angles observ.	Denominations of Point.	Angles.	Spheric Excess & Corr.	Distances.
			° ′ ″		m.
1.	2	Main Station.	42 06 22,7		1824,62
	3	Cut to F. M.	37 59 43,53		1241,90
	3	On the Island.	99 53 53,65		
			179 59 59,88	+ 0,12	

NOTE.

This Paper was followed by a Journal of the "Principal Dates connected with the Survey of the Coast;" but as this Journal was not considered of general interest, and as the paper was already of great length, it has been thought proper to omit it.

INDEX TO NO. XII.